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(54) Title: α 1-3 GALACTOSYLTRANSFERASE GENE AND PROMOTER

(57) Abstract: The present invention provides a recombinant expression cassette comprising an α 1-3 galactosyltransferase promoter operably linked to a polynucleotide for expression. The invention also provides a recombinant mutating cassette comprising a region of homology to an α 1-3 galactosyltransferase genomic sequence. The cassettes can be employed to express foreign genes or to disrupt the native α 1-3 galactosyltransferase genomic sequence, particularly within an animal. Thus, the invention also provides transgenic animals and methods for their production and use.

α 1-3 GALACTOSYLTRANSFERASE GENE AND PROMOTER

TECHNICAL FIELD OF THE INVENTION

This invention relates to the α 1-3 galactosyltransferase gene, promoters
5 therefor, and the use thereof to create transgenic animals.

BACKGROUND OF THE INVENTION

The current shortage of acceptable organs for transplantation is a major health concern. Because the demand for acceptable organs exceeds the supply,
10 many people die each year while waiting for organs to become available. To help meet this demand, research has been focused on developing alternatives to allogenic transplantation. Thus, for example, dialysis has been available to patients suffering from kidney failure, artificial heart models have been tested, and other mechanical systems have been developed to assist or replace failing organs.
15 Such approaches, however, are quite expensive, and the need for frequent and periodic access to such machines greatly limits the freedom and quality of life of patients undergoing such therapy.

Xenograft transplantation represents a potentially attractive alternative to artificial organs for human transplantation. The potential pool of nonhuman
20 organs is virtually limitless, and a successful xenograft transplantation would not render the patient virtually tethered to machines as is the case with artificial organ technology. Host rejection of such cross-species tissue, however, remains a major concern in this area. Some noted xenotransplants of organs from apes or old-world monkeys (e.g., baboons) into humans have been tolerated for months
25 without rejection. However, such attempts have ultimately failed due to a number of immunological factors. Even with heavy immunosuppression to suppress hyperacute rejection, a low-grade innate immune response, attributable in part to failure of complement regulatory proteins (CRPs) within the graft tissue to control activation of heterologous complement on graft endothelium, ultimately leads to
30 destruction of the transplanted organs (see e.g., Starzl, *Immunol. Rev.*, 141, 213-44 (1994)). In an effort to develop a pool of acceptable organs for xenotransplantation into humans, researchers have engineered animals producing human CRPs, an approach which has been demonstrated to delay, but not eliminate, xenograft destruction in primates (McCurry et al., *Nat. Med.*, 1, 423-27
35 (1995); Bach et al., *Immunol. Today*, 17, 379-84 (1996)).

In addition to complement-mediated attack, human rejection of discordant xenografts appears to be mediated by a common antigen: the galactose- α (1,3)-

galactose (gal- α -gal) terminal residue of many glycoproteins and glycolipids (Galili et al., *Proc. Nat. Acad. Sci. (USA)*, 84, 1369-73 (1987); Cooper et al., *Immunol. Rev.*, 141, 31-58 (1994); Galili et al., *Springer Sem. Immunopathol.*, 15, 155-171 (1993); Sandrin et al., *Transplant Rev.*, 8, 134 (1994)). This antigen is chemically related to the human A, B, and O blood antigens, and it is present on many parasites and infectious agents, such as bacteria and viruses. Most mammalian tissue also contains this antigen, with the notable exception of old world monkeys and apes (including humans) (see Joziassse et al., *J. Biol. Chem.*, 264, 14290-97 (1989) and references cited therein)). The antigen is highly immunogenic in humans, and many individuals show significant levels of circulating IgG with specificity for gal- α -gal carbohydrate determinants (see, e.g., Galili et al., *J. Exp. Med.*, 162, 573-82 (1985), Galili et al., *Proc. Nat. Acad. Sci. (USA)*, 84, 1369-73 (1987)). Thus, in hopes of better understanding barriers to xenotransplantation, recent attention has turned to the enzyme mediating the formation of gal- α -gal moieties: α 1-3 galactosyltransferase.

The expression of α 1-3 galactosyltransferase is regulated both developmentally and in a tissue-specific manner. The cDNA for this enzyme has been isolated from many species, including pigs (Hoopes et al., poster presentation at the 1997 Xenotransplantation Conference, Nantes France; Katayama et al., *J. Glycoconj.*, 15(6), 583-99 (1998); Sandrin et al., *Xenotransplantation*, 1, 81-88 (1994), Strahan et al., *Immunogenics*, 41, 101-05 (1995)), mice (Joziassse et al., *J. Biol. Chem.*, 267, 5534-41 (1992)), and cows (Joziassse et al., *J. Biol. Chem.*, 264, 14290-97 (1989)). While authors have proposed to eliminate the gene from xenograft donor animals (Sandrin et al. (1994), *supra*; U.S. Patent 5,821,117 (Sandrin et al.)), gene knock-out procedures generally require knowledge of the genomic structure and sequence beyond the cDNA of a given gene. The genomic organization of the mouse α 1-3 galactosyltransferase homologue has been deduced (Joziassse et al., *J. Biol. Chem.*, 267, 5534-41 (1992)), and human homologues are known to be inactive pseudogenes (see Joziassse et al., *J. Biol. Chem.*, 266, 6991-98 (1991); Larsen et al., *J. Biol. Chem.*, 265, 7055-61 (1990)). However, the genomic organization of an α 1-3 galactosyltransferase homologue from a species that could serve as a xenograft donor for human recipients has yet to be deduced, and no promoter for any α 1-3 galactosyltransferase homologue gene is known. As such, there exists a need for methods and reagents for facilitating xenotransplantation between species, particularly between species exhibiting differential expression of the gal- α -gal epitope.

BRIEF SUMMARY OF THE INVENTION

The present invention provides a recombinant expression cassette comprising an α 1-3 galactosyltransferase promoter operably linked to a polynucleotide for expression. The invention also provides a recombinant
5 mutating cassette comprising a region of homology to an α 1-3 galactosyltransferase genomic sequence. The cassettes can be employed to express foreign genes or to disrupt the native α 1-3 galactosyltransferase genomic sequence, particularly within an animal. Thus, the invention also provides transgenic animals and methods for their production and use. These aspects of the
10 invention, as well as additional inventive features, will be apparent from the accompanying drawing, sequence listing, and the following detailed description.

BRIEF DESCRIPTION OF THE DRAWINGS

Figures 1A through 1I depict the genomic organization porcine α 1-3
15 galactosyltransferase gene. Figure 1A depicts all introns and exons of the gene, indicating the size of the respective elements. Figures 1B through 1I depict alternatively spliced variants isolated from pig aortic endothelial cells.

Figure 2 depicts the organization of a portion of the porcine α 1-3 galactosyltransferase promoter.

20 Figure 3 depicts the organization of the alternate splicing patterns observed in the expression of the human untranslated α 1,3 galactosyltransferase pseudogene.

DETAILED DESCRIPTION OF THE INVENTION

25 In a first aspect, the present invention provides a recombinant expression cassette in which an α 1-3 galactosyltransferase promoter is operably linked to a polynucleotide for expression. The expression cassette is "recombinant" in that within the inventive cassette, the polynucleotide for expression is other than one encoding α 1-3 galactosyltransferase. The promoter and the polynucleotide are
30 "operably linked" in that an event at the promoter (e.g., binding of cellular transcription factors and other DNA binding proteins) precipitates expression (i.e., transcription) of the polynucleotide. So long as this operable linkage is maintained, the cassette can include elements other than the α 1-3 galactosyltransferase promoter and the polynucleotide for expression. For
35 example, the cassette can contain polyadenylation sequences, repressors, enhancers, splice signals, signals for secretion (see, e.g., U.S. Patent 4,845,046 and European Patent EP-B-319,641), etc. Moreover, the expression cassette can

include more than one polynucleotide operably linked to the α 1-3 galactosyltransferase promoter, (e.g., multiple coding sequences separated by internal ribosome entry sites).

- The α 1-3 galactosyltransferase promoter can be derived from any species normally expressing the gene. Thus, for example, the promoter can be derived from the bovine, porcine, or murine α 1-3 galactosyltransferase genes. Examples of such promoters are set forth at SEQ ID Nos:1-6. However, the α 1-3 galactosyltransferase promoter is not limited to one of these sequences, as it can be an active fragment of one of these sequences or a derivative of one of these sequences having one or more mutations (e.g., point mutations, substitutions, insertions, deletions, etc.). Furthermore, given the instant disclosure, it is within the ordinary skill of the art to assay regions of the α 1-3 galactosyltransferase gene unrelated to SEQ ID NOs:1-6 for promoter activity, and the inventive expression cassette can include any α 1-3 galactosyltransferase promoters so identified.
- Suitable promoters can be readily identified by construction an expression cassette in which the derivative sequence is operably linked to a desired reporter gene (e.g., RNA for detection by Northern hybridization, or DNA encoding CAT, luciferase, green-fluorescent peptide, β -galactosidase, etc.) and introducing the cassette into a suitable environment for transcription and (where appropriate) translation.
- Subsequently, promoter activity is detected by assaying for the presence of the reporter by standards methods (e.g., Northern hybridization, Southern hybridization, enzymatic detection, immunohistochemistry, etc.).

- Within the expression cassette, the α 1-3 galactosyltransferase promoter can be operably linked to any desired coding polynucleotide. Generally, where expression of a given gene or factor is desired, the skilled artisan will be in possession of the sequence of the coding polynucleotide. Thus, the polynucleotide can be expressed as a bioactive RNA molecule (e.g., an antisense RNA or a ribozyme). Alternatively, the polynucleotide can encode a protein of interest, and in this embodiment, the polynucleotide can be or comprise cDNA or genomic DNA.

- Where the polynucleotide encodes a protein, any desired protein can be so encoded, and it need not be syngenic to the species from which the promoter is derived. Thus, for example, the cassette can be employed in animals to produce proteins facilitating growth or bulking of the animal (e.g., bovine or human growth factor) for conferring resistance to disease or parasites. Other encoded proteins can be enzymes such as sulfo- or glycosyltransferases, (e.g., a fucosyltransferase, a galactosidase, a galactosyltransferase, a β -acetylgalactosaminyltransferase, an

N-acetylglycosaminyltransferase, an N-acetylglucosaminyltransferase, a sialyltransferase, etc.). Where the expression cassette is employed to generate tissue or organs for xenotransplantation into an organism lacking gal- α -gal antigens (as described below), preferably the polynucleotide encodes a Type I fucosyltransferase, a Type II fucosyltransferase, an α 2-3 sialyltransferase, or an α 2-6 sialyltransferase from any species, the coding sequences of which are known (see, e.g., Larsen et al., *Proc. Nat. Acad. Sci. (USA)*, 87, 6674-78 (1990); Kelly et al., *J. Biol. Chem.*, 270(9), 4640-49 (1995), *J. Biol. Chem.*, 268(30), 22782-87 (1993), Weinstein et al., *J. Biol. Chem.*, 262(36), 17735-43 (1987)).

The expression cassette can be constructed by conventional methods of molecular biology (e.g., direct cloning by ligation, site specific recombination using recombinases, such as the flp recombinase or the cre-lox recombinase system (reviewed in Kilby et al. *Trends Genet.*, 9, 413-21 (1993)), homologous recombination, and other suitable methods). Typically, the promoter sequence is introduced into a vector 5' (i.e., "upstream") of the coding polynucleotide and any other elements (e.g., ribosome entry sites, polyadenylation sequences, etc.), after which the construct is subcloned and grown in a suitable host organism (e.g., yeast, bacteria, etc.) from which it can be isolated or substantially (and typically completely) purified by standard methods. Thus, the invention provides a vector (preferably an isolated or substantially purified vector) including a recombinant expression cassette as set forth above. Such a vector can be any desired type of vector, such as naked DNA vectors (e.g., oligonucleotides or plasmids); viral vectors (e.g., adeno-associated viral vectors (Berns et al., *Ann. N.Y. Acad. Sci.*, 772, 95-104 (1995)), adenoviral vectors (Bain et al., *Gene Therapy*, 1, S68 (1994)), bacteriophages, baculovirus vectors (see, e.g., Luckow et al., *Bio/Technology*, 6, 47 (1988)), herpesvirus vectors (Fink et al., *Ann. Rev. Neurosci.*, 19, 265-87 (1996)), packaged amplicons (Federoff et al., *Proc. Nat. Acad. Sci. USA*, 89, 1636-40 (1992)), papilloma virus vectors, picornavirus vectors, polyoma virus vectors, retroviral vectors, SV40 viral vectors, vaccinia virus vectors) or other vectors (e.g., a cosmid, a yeast artificial chromosome (YAC), etc.). Of course, the vector can (and typically does) contain elements in addition to the expression cassette that are appropriate to the type of vector (e.g., origins of replication, marker genes, genes conferring resistance to antibiotics, etc.). The insertion of the expression cassette can disrupt one or more of these elements, if desired, or the cassette can be inserted between genetic elements to minimize perturbation of the backbone vector.

Where the vector is a viral vector, preferably it is replication incompetent. Thus, for example, an adenoviral vector preferably has an inactivating mutation in at least the E1A region, and more preferably in region E1 (i.e., E1A and/or E1B) in combination with inactivating mutations in region E2 (i.e., E2A, E2B, or both
5 E2A and E2B), and/or E4 (see, e.g., International Patent Application WO 95/34671). An AAV vector can be deficient in AAV genes encoding proteins associated with DNA or RNA synthesis or processing or steps of viral replication (e.g., capsid formation) (see U.S. Patents 4,797,368, 5,354,768, 5,474,935, 5,436,146, and 5,681,731). Where the vector is a retroviral vector, the cis-acting
10 encapsidation sequence (E) essential for virus production in helper cells can be deleted upon reverse transcription in the host cell to prevent subsequent spread of the virus (see, e.g., U.S. Patent 5,714,353). Where the vector is a herpesvirus, inactivation of the ICP4 locus and/or the ICP27 cassette renders the virus replication incompetent in any cell not complementing the proteins (see, e.g., U.S.
15 Patent 5,658,724, see also DeLuca et al., *J. Virol.*, 56, 558-70 (1985); Samaniego et al., *J. Virol.*, 69(9), 5705-15 (1996)).

To use the inventive recombinant expression cassette, it is introduced into a eukaryotic cell in a manner suitable for the cell to express the coding polynucleotide. A vector harboring the recombinant expression cassette is
20 introduced into a eukaryotic cell by any method appropriate for the vector employed, which generally are well-known in the art. Thus, plasmids are transferred by methods such as calcium phosphate precipitation, electroporation, liposome-mediated transfection, microinjection, viral capsid-mediated transfer, polybrene-mediated transfer, protoplast fusion, etc. Viral vectors are best
25 transferred into the cells by infecting them.

Depending on the type of vector, it can exist within the cell as a stable extrachromosomal element (which can even be heritable, see e.g., Gassmann, M. et al., *Proc. Natl. Acad. Sci. (USA)*, 92, 1292 (1995)) or it can integrate into the host cell's chromosomes. Thus, the invention provides a chromosome including a
30 recombinant expression cassette such as described above, as well as a cell including such a cassette (and such a chromosome). The α 1-3 galactosyltransferase promoter of the expression cassette can be native to such a cell or chromosome, or it can be exogenous to the cell or chromosome. Where the promoter is native to the cell or chromosome, preferably the polynucleotide for
35 expression within the cassette (the non-native polynucleotide) displaces the operable linkage between the native polynucleotide encoding α 1-3 galactosyltransferase such that it is no longer operably linked to the native α 1-3

galactosyltransferase promoter. Such displacement can be accomplished where the non-native polynucleotide is cloned between the promoter and the native polynucleotide (i.e., upstream of the native polynucleotide), especially where the non-native polynucleotide contains one or more transcriptional termination signals (preferably in all three putative reading frames). Of course, the non-native polynucleotide also can be introduced into the locus such that it destroys the native exon/intron boundaries and/or introduces inactivating mutations (e.g., deletions, insertions, frame-shifts, etc.) into the native coding sequence.

Preferably, the transgenic cell presents a suitable microenvironment for the coding polynucleotide within the expression cassette to be expressed. In many instances, the transgenic cells can be used to study the tissue specificity, dynamics, and kinetics of the promoter, for example by assaying for the expression of the polynucleotide within the cells. However, as the absence of activity is as useful as the presence of promoter activity in these contexts, any cell can be employed for such purposes; such a cell can be *in vivo* or *in vitro*. Preferably, the cell is derived from a species syngenic to the source of the promoter so that, by virtue of the properties of the α 1-3 galactosyltransferase promoter present within the expression cassette, the polynucleotide within the cassette is expressed within such transgenic tissues, organs, or animals with the same kinetics and tissue specificity as the native α 1-3 galactosyltransferase gene in wild-type animals. Where the cells are *in vivo*, they are typically cells of a mammal (e.g., human cells), and can be any type of cells. Suitable cells for use *in vitro* include yeast, protozoa (e.g., *T. cruzi* epimastigotes), cells derived from any mammalian species (e.g., VERO, CV-1, COS-1, COS-7, CHO-K1, 3T3, NIH/3T3, HeLa, C1271, BS-C-1 MRC-5, etc.), insect cells (e.g., *Drosophila* Snyder cells), or other such cells. In other applications, the cell can be employed to construct transgenic tissues, organs, or animals, as described below, in which case the cell typically is a spermatozoon, ovum, zygote, primordial germ cells, or embryonic stem cell.

In another embodiment, the invention provides a method of mutating a region of a chromosome comprising an α 1-3 galactosyltransferase gene. In accordance with the inventive method, a recombinant mutating cassette comprising a region of homology to the α 1-3 galactosyltransferase gene is recombined with a chromosome which has an α 1-3 galactosyltransferase gene such that homologous recombination occurs between the cassette and the chromosome. As a result of the homologous recombination, a mutation is introduced into the native α 1-3 galactosyltransferase chromosomal gene sequence.

Thus, the final step of the method involves screening for successful recombination.

The inventive method employs a recombinant mutating cassette including at least a first region of homology to an α 1-3 galactosyltransferase genomic sequence, and the invention provides such a cassette. Within such a cassette, this first region of homology is adjacent to either to at least one polynucleotide for insertion or to a second region of homology. The mutating cassette is "recombinant" in that neither the second region of homology nor the polynucleotide for insertion is adjacent to the first α 1-3 galactosyltransferase genomic sequence in its native state (i.e., within a chromosome).

The insertion cassette can include more than one polynucleotide for insertion and/or more than one region of homology to all or a portion of the α 1-3 galactosyltransferase genomic sequence. Indeed, where the cassette includes a region for insertion, preferably it has at least two regions of homology flanking the region for insertion. Where more than one region of homology is present, whether adjacent to each other or flanking a region for insertion, the cassette can be used to replace any span of the target chromosomal genomic sequence that lies between the two homologous chromosomal regions. Where multiple regions of homology are present, they should generally be arrayed in the same 5' to 3' orientation relative to one another.

A region of homology can be homologous to any portion of the genomic sequence of an α 1-3 galactosyltransferase gene or the antisense strand thereof. The region can be homologous to the gene of any desired species, such as those discussed above, and it can be homologous to an intron, an exon, a promoter sequence, or any other desired sequence from the genomic DNA. To this end, regions of homology can be selected from the promoter sequences disclosed in SEQ ID NOs:1-6. Alternatively (or additionally) a region of homology can be selected from a portion of the genomic sequence from an α 1-3 galactosyltransferase homologue. In this light, some of the murine sequences have been published (see, e.g., Joziassse et al., *J. Biol. Chem.*, 267, 5534-41 (1992)), and additional portions are set forth as SEQ ID NOs: 17-25. Portions of the porcine genomic sequence are disclosed herein as SEQ ID NOs: 7-16. Portions of the human α 1,3 galactosyltransferase pseudogene genomic sequences are set forth at SEQ ID NOs: 35-42, and various (untranslated) human cDNA transcripts are set forth as SEQ ID NOs: 27-34, and those from Rhesus monkeys are set forth at SEQ ID NOs: 43-44. These sequences disclosed herein, as well as the published murine sequences, include the intron/exon boundaries from which one of skill in

the art can isolate additional intronic genomic sequences by techniques such as genome walking, 5' RACE, 3' RACE, etc.

A region of homology to the genomic sequence of an α 1-3 galactosyltransferase gene need not be an exact complement to the genomic sequence; however, the region must be sufficiently homologous to the α 1-3 galactosyltransferase gene to permit homologous recombination between the cassette and the genomic DNA *in vivo*. Indeed, in some embodiments (e.g., for introducing point mutations into the genomic sequence), a region of homology preferably contains some mismatched bases. Thus, typically, the region of homology will bear at least about 75 % homology to a portion of the α 1-3 galactosyltransferase gene or its antisense strand (such as at least about 85 % homology to a portion of the α 1-3 galactosyltransferase gene or its antisense strand), and more typically the region of homology will bear at least about 90 % homology to a portion of the α 1-3 galactosyltransferase gene or its antisense strand (such as at least about 95 % or even at least about 97 % homology to a portion of the α 1-3 galactosyltransferase gene or its antisense strand). Any commonly employed method (e.g., BLAST database searching) for calculating percent homology can be used to select a suitable region of homology. Similarly, while the length of the region of homology is not critical, it should be sufficiently long to facilitate homologous recombination between the cassette and the genomic DNA *in vivo*. Thus, typically the region of homology will be at least about 50 nucleotides long (such as at least about 75 or 100 bases long), and more typically it will be at least several hundred bases long (such as at least about 250, 500, or even 750 bases long). Indeed, in many applications, the region of homology preferably is several thousand bases long to maximize the likelihood of homologous recombination *in vivo*. The ideal length of a region of homology depends in part on the number of such regions within the cassette – where one or few regions of homology are present, they should be longer to facilitate recombination between the cassette and the genomic DNA; conversely, where the cassette contains several regions of homology, they can be shorter without reducing the likelihood of recombination events.

Where present within the cassette, a region for insertion can be or comprise any DNA which is desired to be introduced into the genomic sequence of an α 1-3 galactosyltransferase gene. Thus, the region can comprise genetic regulatory elements (e.g., enhancers, promoters, repressors, etc., the sequences of which are known) or consensus binding sites for DNA-binding proteins (e.g., restriction endonucleases, transcription factors, etc.). In many applications, a region for

insertion can comprise a polynucleotide for expression, such as those set forth above, or even expression cassettes. A preferred polynucleotide for insertion is an expression cassette for expressing a positive marker flanked by FRT sites, thus facilitating the identification of chromosomes into which the polynucleotide for
5 insertion has integrated as well as excision of the cassette.

The mutating cassette can be constructed by any desirable molecular techniques, and typically, the mutating cassette will be engineered within a vector, such as those set forth above. Typically, the vector is a gene transfer vector suitable for introducing the cassette into a host cell. In addition to the region(s) of
10 homology and the polynucleotide for insertion elements, the mutating cassette can have other components, such as, for example, an expression cassette, a region of homology to other genes or chromosomal regions, a polyadenylation sequence, etc., and it is preferred that the insertion cassette comprises a cassette for expressing at least one marker gene (which may be or comprise the polynucleotide
15 for insertion). Such a marker can be either positive (conferring a visible phenotype to the cells) or negative (killing cells or rendering non-recombinant cells growth-impaired), and both can be used in conjunction. Examples of such positive and negative selection markers are the neosporin resistance (neo^R) gene, the hydromycin resistance (hyg^R) gene, and a thymidine kinase gene (e.g., HSV
20 tk); other suitable markers are known in the art (see, e.g., Mansour et al., *Nature*, 336, 348-52 (1988); McCarrick et al., *Transgen. Res.*, 2, 183-90 (1993)). A marker gene sequence can be bordered at both ends by FRT DNA elements, and/or with stop codons for each of the three putative reading frames being inserted 3' to the desired DNA sequence. Presence of the FRT elements permits the marker to
25 be deleted from the targeted chromosome, and the stop codons ensure that the $\alpha 1,3$ galactosyltransferase gene remains inactivated following deletion of the selectable marker, if inactivation is the desired result of the use of the mutating cassette. The relative orientations of the positive and negative selectable markers are not critical. However, where a positive marker is employed, it should be
30 located between regions of homology, while any negative marker should be outside the regions of homology, either 5' or 3' to those regions.

In accordance with the inventive method, homologous recombination occurs between the $\alpha 1-3$ galactosyltransferase genomic chromosomal DNA and the region (or regions) of homology in the mutating cassette. Where more than
35 one region of homology is present in the cassette, any portion of the genome lying between the homologous target sequences is replaced by whatever sequence lies between the regions of homology in the cassette. Thus, where the mutating

cassette contains a region for insertion flanked by two regions of homology, it will be introduced into the genomic sequence adjacent to the sites of homology, replacing that portion of the genomic sequence. Of course, where the two flanking regions of homology are normally adjacent to each other in the chromosomal sequence, the region for insertion is introduced into the chromosome without replacing any native sequence. Similarly, where no region for insertion is present within the cassette, that portion of the chromosome lying between the two regions of homology in the cassette is deleted as a result of the recombination events. Where the cassette contains a region of homology that differs slightly from the homologous sequence within the genome, it can be employed to introduce point mutations into the genomic sequence.

While the recombination event can occur *in vitro*, typically such homologous recombination occurs within a host cell between an exogenous vector containing the cassette and a chromosome within the host cell containing an $\alpha 1$ -3 galactosyltransferase genomic sequence. Thus, the present invention provides a cell harboring a mutating cassette, as described above. The vector can be introduced into the host cell by any appropriate method, such as set forth above. Commonly, however, the vector is introduced into small cells (e.g., embryonic stem cells) by electroporation and into large cells (e.g., ova or zygotes) by microinjection. Where microinjection is employed, the vector preferably is injected directly into a nucleus or pronucleus of the cell.

The last step in the method is to screen for successful recombination events. Any assay to detect such events can be employed in the context of the inventive method. In accordance with one such assay, chromosomal DNA is screened by PCR or Southern hybridization. For example, where the mutating cassette is designed to delete a portion of the $\alpha 1$ -3 galactosyltransferase genomic sequence, the absence of signal using a probe or primer directed against the region to be deleted indicates a positive recombination event. Conversely, where the cassette includes a region for insertion, a positive result using a probe or primer directed against the region for insertion is indicative of a positive recombination event. Of course, the chromosomal DNA can be sequenced to confirm the correct insertion/deletion/replacement. Where recombination is directed within cells, the events can be screened by assaying for any markers present in the mutating cassette.

By employing the inventive method, one of skill in the art can use the inventive mutating cassette to introduce targeted deletions, insertions, or replacement mutations into any predefined site within the $\alpha 1$ -3

galactosyltransferase genomic sequence. Any desired amount or portion of the gene can be thus deleted, which can lead to complete inactivation of the gene. For introducing inactivating mutations into the gene, preferably at least one region of homology is selected to recombine with the promoter (to inactivate it) or exons 4-
5 9, which contain the coding sequences. Similarly, the inventive method can introduce functional expression cassettes in place of the α 1-3 galactosyltransferase gene, which can be under the control of the native α 1-3 galactosyltransferase promoter or an exogenous promoter within the cassette (especially where the native α 1-3 galactosyltransferase promoter is destroyed). Thus, the present
10 invention provides a recombinant chromosome containing such a mutation, and a recombinant cell comprising such a chromosome.

As mentioned above, the invention provides recombinant cells and chromosomes comprising a recombinant expression cassette comprising an α 1-3 galactosyltransferase promoter or a mutating cassette, as described above. Indeed,
15 as a result of using these reagents and methods, the invention also provides a cell having a mutant α 1-3 galactosyltransferase genomic sequence, as described above. While any cell having such exogenous genetic sequences is within the scope of the invention, preferably the cells are suitable for constructing a recombinant animal, and are most preferably totipotent cells. Thus, preferred cells are embryonic stem
20 (ES) cells, ova, primordial germ cells (PGCs), and zygotes. ES cells and PGCs are especially preferred because such cells can be obtained and cultured in relatively large numbers relative to ova and zygotes. Using such cells, a transgenic animal having an expression cassette comprising an α 1-3 galactosyltransferase promoter or a disruption in this gene can be constructed by methods known in the art (see
25 e.g., U.S. Patents 5,850,004 (MacMicking et al.), 5,942,435 (Wheeler), 5,523,226 (Wheeler), and 5,175,383; White et al., *Transplant. Int.*, 5, 648-50 (1992); McCurry et al., *Nat. Med.*, 1, 423-427 (1995); Hogan et al., *Manipulating the Mouse Embryo*, Cold Spring Harbor Laboratory, Cold Spring Harbor, N.Y. (1986); Hammer et al., *Nature*, 315, 680 (1985); Murray et al., *Reprod. Fert. Devl.*,
30 1, 147, (1989); Purselet et al., *Vet. Immunol. Histopath.*, 17, 303 (1987); Rexroad et al., *J. Reprod. Fert.*, 41, (suppl.), 119 (1990); Rexroad et al., *Molec. Reprod. Devl.*, 1, 164 (1989); Simonset al., *BioTechnology*, 6, 179 (1988); Vizeet al., *J. Cell. Sci.*, 90, 295 (1988); Wagner, J. *Cell. Biochem.*, 13B (suppl.), 164 (1989); Thomas et al., *Cell*, 51, 503 (1987); Capecchi, *Science*, 244, 1288 (1989); Joyner et al.,
35 *Nature*, 338, 153 (1989); Ausubelet al., *Cur. Prot. Mol. Biol.*, John Wiley & Sons (1987)).

Where ova and zygotes are employed, after the introduction of the cassette, they can be implanted into surrogate mothers to develop into adult animals.

Where ES cells or PGCs are employed, after the introduction of the cassette, they typically are further manipulated (e.g., by injection into a blastocyst or morula, co-culture with a zona pellucida-disrupted morula, fusion with an enucleated
5 zygote, etc.) such that their mitotic descendants are found in a developing embryo. Such an embryo typically is a chimera composed of normal embryonic cells as well as mitotic descendants of the introduced ES cells or PGCs. Alternatively, the genome of an ES cell or PGC can be incorporated into an embryo by fusing the ES
10 cell/PGC with an enucleated zygote to create a non-chimeric embryo in which all nuclei are mitotic descendants of the fused ES cell/PGC nucleus. In any event, to produce a transgenic animal, the embryo or zygote is implanted into a pseudopregnant animal, which, after suitable gestation, gives birth to an animal containing the mutant chromosome containing the cassette in its germ line (if a
15 chimera) or possibly all of its cells. Of course, as mentioned above, where the animal is engineered to include a non-mutating expression cassette, it can be inherited as an extrachromosomal plasmid (Gassmann, M. et al., *supra*). However constructed, the presence of the recombinant allele can be confirmed by performing Northern hybridization or rt-PCR on RNA isolated from the animal in
20 question.

After birth and sexual maturation, a chimeric animal can be mated to generate a heterozygous animal comprising a disrupted α 1-3 galactosyltransferase gene or recombinant expression cassette (integrated or extrachromosomal) including a α 1-3 galactosyltransferase promoter. Heterozygotes can be crossed to
25 produced a homozygous strain. Such animals having a recombinant expression cassette including an α 1-3 galactosyltransferase promoter, as discussed above, will express the polynucleotide for expression of such cassette within the same tissue types and with the same kinetics as a wild-type animal of the same species and strain expresses the α 1-3 galactosyltransferase gene. Of course, homozygous
30 transgenic animals of the present invention having a disruption in the α 1-3 galactosyltransferase gene will produce altered forms of the protein or no functional protein at all. Desirably, the phenotype of such "knock out" animals relative to an animal having a wild type α 1-3 galactosyltransferase gene is a markedly increased time of survival of cells isolated or derived from the
35 transgenic animal in the presence of human serum, which can be assessed by any desired method (see, e.g., Osman et al., *Proc. Nat. Acad. Sci. (USA)*, 94, 14677-82 (1997)).

The inventive transgenic animals are useful for any use to which animals can be put, and they can be any desired species (e.g., pigs, cows, mice, cats, dogs, etc.). Transgenic mice in which a reporter gene is operably linked to the α 1-3 galactosyltransferase promoter are valuable reagents for assessing the activity and specificity of the promoter. Transgenic livestock (e.g., pigs, cows, goats, and the like) having an inventive expression cassette in which a growth hormone is expressed under the control of the α 1-3 galactosyltransferase promoter can be matured or bulked better than commonly employed strains. Tissue obtained from a transgenic animal according to the present invention can be implanted into a host according to standard surgical methods, and the invention concerns a method of xenotransplantation from a transgenic animal as described herein. The invention also provides a transgenic organ consisting essentially of transgenic cells engineered as described above (e.g., a lung, a heart, a liver, a pancreas, a stomach, an intestine, a kidney, a cornea, skin, etc.), particularly for use in the method of transplantation. The host can be any animal host, such as a pig, a dog, a cat, a cow, a goat, etc. Of course, the recipient can be a human as well, in which case the source animal preferably is a pig.

Transgenic animals lacking a functional α 1-3 galactosyltransferase gene are attractive sources of organs and tissues for xenotransplantation into primates, especially humans, because the tissues of such animals lack the highly antigenic gal- α -gal epitope. Similarly, transgenic pigs having a recombinant expression cassette in which a coding sequence for Type I fucosyltransferase, a Type II fucosyltransferase (especially α (1,2) fucosyltransferase), an α 2-3 sialyltransferase, or an α 2-6 sialyltransferase is operably linked to the α 1-3 galactosyltransferase promoter also are suitable sources of xenotransplantation tissues, as these encoded enzymes compete for the same substrate as α 1-3 galactosyltransferase, and their presence can reduce (preferably below an antigenic threshold) the gal- α -gal antigens in tissues derived from such animals. Indeed, α (1,2) fucosyltransferase converts this substrate into the universally-tolerated H antigen (i.e., the "O" blood-type antigen) and also blocks the addition of the α 1,3 gal moiety. As such, a gene encoding α (1,2) fucosyltransferase is an especially preferred polynucleotide for expression to be included within the inventive recombinant expression cassette. A preferred source animal for xenotransplantation tissues (and by extension the tissues themselves) preferably contains a disruption in the α 1-3 galactosyltransferase gene as well as having a recombinant expression cassette in which a coding sequence for Type I fucosyltransferase, a Type II fucosyltransferase (especially α (1,2)

fucosyltransferase), an α 2-3 sialyltransferase, or an α 2-6 sialyltransferase is operably linked to the α 1-3 galactosyltransferase promoter. More preferably, the animal contains a disruption in the native promoter of α 1-3 galactosyltransferase and an α (1,2) fucosyltransferase coding sequence under the control of its own
5 promoter. Most preferably, the source animal also expresses exogenous human complement regulatory proteins, as discussed above, to further minimize host resistance of the xenograft tissue.

It will be apparent that a transgenic animal created in accordance with the invention can have the exogenous gene cloned in place of the native α 1,3
10 galactosyltransferase gene (i.e., a “knock-in” approach). Indeed, in many embedment such a “knock-in” approach is preferable, for example to avoid the potential of the development of congenital cataracts in purely “knock-out” animals (e.g., as a result of opportunistic infections of microbes bearing the gal- α -gal motif). Indeed, such an approach can afford a safe alternative to broadband
15 antibiotics in livestock and pets, a current public health concern. In this respect, the invention can be employed to create heartier and healthier livestock and pets.

While one of skill in the art is fully able to practice the instant invention upon reading the foregoing detailed descriptions, in conjunction with the drawing and the sequence listing, the following examples will help elucidate some of its
20 features. In particular, these examples indicate how the genomic structure of the porcine α 1-3 galactosyltransferase gene is elucidated, and how the identity and activity of the α 1-3 Galactosyltransferase promoter is assessed. As these examples are presented for purely illustrative purposes, they should not be used to construe the scope of the invention in a limited manner, but rather should be seen
25 as expanding upon the foregoing description of the invention as a whole.

Many experiments described in these examples employed well known techniques and reagents (see, e.g., Sambrook et al., *Molecular Cloning: A Laboratory Manual*, 2d edition, Cold Spring Harbor Press (1989)). Accordingly, in the interest of brevity, the examples do not present the experimental protocols in
30 detail. In the experiments, enzymatic isolation and culture of porcine aortic endothelial cells (PAEC) was performed. PAEC were maintained in Dulbecco's modified essential medium (DMEM) supplemented with 10% fetal bovine serum (FBS), 10,000 units of Heparin (ELKINS-SINN, Inc., Cherry Hill, NJ), 15 mg of endothelium growth supplement (Collaborative Biomedical Product Inc., Bedford,
35 MA), L-glutamine, and penicillin-streptomycin. RNA was obtained from the organs of pigs (Brain, Heart, Spleen, Gut, and Thymus) and PAEC using Trizol reagent

(Gibco Ltd.). Primers used to clone and identify regions of the porcine, murine, human, and Rhesus monkey genes are set forth at SEQ ID NOs: 45-96.

Example 1

5 This example describes the identification of the 5' untranslated region and genomic structure of the porcine α 1-3 galactosyltransferase gene.

A comparison of published sequences for the α 1-3 galactosyltransferase cDNA (Hoopes et al., *supra*, Katayama et al., *supra*; Sandrin et al., *supra*; and Strahan et al., *supra*) revealed a divergence in the 5' boundary. Some of these
10 cDNA contain putative 5' untranslated sequences that bear a high (> 70 %) homology to murine sequences identified as the second exon, and it was hypothesized that this region is conserved as an exon in the porcine genome as well.

Further 5' sequence was cloned using 5' RACE, and the putative
15 transcription initiation site was probed by S1 protection assay, using standard protocols. Briefly, a plasmid containing the upstream genomic sequence was digested with restriction enzyme, Pml I, and linearized. The DNA was phosphorylated with shrimp alkaline phosphatase, heated to inactivate the enzyme, and then precipitated with ethanol. The linearized plasmid was digested again
20 with Bgl II to yield a probe fragment, which was then end-labeled with γ -³²P-ATP.

The probe was purified using G-25 sephadex, and about 16 μ l was mixed with 20 μ g of total RNA from pig aortic endothelial cells (PAEC), pig brain, and yeast (control), and the aliquots were coprecipitated using NH₄OAc and ethanol. Pellets were resuspended in a standard hybridization buffer, heated to 95 °C for 3-
25 4 minutes, and then incubated at 42 °C overnight.

After incubation, the yeast sample was split into two aliquots, and to each was added a standard S1 nuclease buffer. S1 nuclease was added to one aliquot, while the other did not receive the enzyme. The PAEC and brain samples each received the enzyme and the buffer. All samples were incubated for 30 minutes at
30 37 °C, after which the reactions were stopped by the addition of a standard S1 inactivation buffer. Following the reaction, the samples were then precipitated, resuspended in 5 μ l of a standard gel loading buffer, and resolved using a 6% denaturing polyacrylamide gel.

The data revealed at least 8 separate alternatively spliced transcripts from
35 PAEC, and additional splicing patterns from brain transcripts. Analysis of these sequences revealed three potential upstream exons (1, 1A, and 2), the boundaries of which comply with the AG-GT consensus, and six coding exons (4-9) also were

identified, which agreed with published results. Interestingly, the pig sequence seemingly lacks upstream exon 3 of the mouse 5' untranslated region. The overall organization of the pig genome is depicted in Figure 1. Alternatively spliced forms isolated from PAED are indicated in Figures 1B through 1I. Exon 1A is
5 observed in transcripts isolated from brain tissue.

As mentioned, the transcripts obtained from PAEC and brain revealed several alternative splicing patterns. Using the genomic clone, intronic sequences were identified by "gene walking" using the method and reagents supplied with the UNIVERSAL GENEOMEWALKER™ KIT (Clontech Labs., Inc.). Primers
10 (Seq ID NOs:41-56) were designed to hybridize with the cDNA, and also to the adapter sequence supplied with the Clontech kit. A series of nested PCR reactions was then performed to clone SEQ ID NOs:7-16, which were sequenced. From these results, the intron/exon boundaries were elucidated.

Summing the nucleotides of all identified exons predicts a transcript of
15 about 3.8 kb. This prediction was assessed by Northern analysis. 20 µg of total RNA from PAEC, and pig brain, heart, spleen, gut, and thymus, were respectively separated on formamide agarose gels, and electrotransferred onto nylon membrane. The blots were hybridized with radiolabeled probes ($2.5-4.0 \times 10^4$ cpm/ml) specific for pig GT exon 1 and exon 9 identified. The blots were exposed
20 to Bio-MAX films (Eastman Kodak Co., Rochester, NY) for 6 days with intensifying screen. The results revealed primary transcripts of between 3.5-3.8 kb, in accordance with the predicted size and the published size for the bovine transcript.

25 **Example 2**

This example describes the identification of the 5' untranslated region and organization of the murine $\alpha 1$ -3 galactosyltransferase gene.

To identify the 5' and 3' ends of $\alpha 1,3$ GT gene transcripts, 5'- and 3'-RACE procedures were performed using the Marathon cDNA Amplification Kit
30 (Clontech) with the spleen poly A⁺ RNA of Balb/C adult male as template. To identify exon-intron boundaries or 5'- and 3'-flanking region of the transcripts, Murine GenomeWalker libraries were constructed using the Universal GenomeWalker Library Kit (Clontech) with Balb/C genomic DNA.

The results of these experiments revealed several genomic sequences,
35 which are set forth at SEQ ID NOs: 17-25. The deduced 5' untranslated nucleotide sequences are longer by 56 bp than previously reported (Joziassse et al., *J. Biol. Chem.*, 267, 5534-41 (1992)). The relative intensity of Luciferase activity

by the pGL3/1280 construct was 15-fold higher than that of pGL3-Basic. The 3'-RACE revealed an extended 3'-UTR sequence 30 bp more than previously reported (*Id.*), but no other 3' UTR exon usage. The overall length of the transcript was 2586 bp, 89 bp longer than previously reported (*Id.*).

- 5 An overall comparison of 5'-UTR of cDNA sequences of the porcine (747 bp) and murine (492 bp) α 1,3GT gene indicates that the homology is observed only in the region of exon 2 (71.7%). Exon 3 observed in mice is not observed in the pig. Murine exon 1 shows no homology with porcine exon 1.

10 **Example 3**

This example describes the identification of the organization of the human and Rhesus monkey α 1-3 galactosyltransferase untranslated pseudogene.

- Working from published partial sequence of the human α 1,3 GT ninth exon, primers were designed to identify the start and end of the gene by 5'-RACE, 3'RACE and rtPCR, as described above. Several alternate transcripts were identified, and these are set forth as SEQ ID NOs:27-34. The sequences were compared to those of other species employing a formula based on the consensus motif of the splicing acceptor junction: total number of pyrimidines plus 1 (for a branched A) among forty nucleotides per junction. Intron exon boundaries were confirmed as discussed above (see SEQ ID NOs: 35-42). The organization of the alternative splicing patterns observed is indicated in Figure 3.

- Using similar techniques, primers were designed based on a partial published sequence (Genbank Accession No. M73306) having homology to exon 9. Initially, 3'RACE showed only poly-A tails, evidence that transcripts exist. 5'-RACE results revealed sequences of high homology to those α 1,3 sequences previously identified (e.g., porcine, bovine and murine), consistent with the identity of the sequence as the Rhesus pseudogene. The sequence of the Rhesus monkey transcripts are set forth at SEQ ID NOs: 43 and 44.

30 **Example 4**

This example describes the identification of the porcine, murine, and bovine α 1-3 galactosyltransferase promoters.

- Using PCR and restriction digestions, various sized fragments between nucleotides 1981 and 2992 of SEQ ID NO:7 (porcine) and between nucleotides 375 and 1325 (murine) were generated. The fragments were cloned into a plasmid such that they were operably linked to a luciferase coding sequence. PAEC were then transfected with these constructs and probed for luciferase activity, along

with a positive and a negative (no promoter) control. All fragments exhibited significantly greater promoter activity over the negative control (between about 15% and 90 % relative light units, as compared to the positive control, the negative control exhibiting no luciferase activity). These results indicate that the regions are promoters and that the 5'-RACE results discussed in Examples 1 and 2 most likely represent the potential transcription initiation site (TIS). Moreover, sequence analysis of these regions reveals the presence of at least 8 SP1 or GC boxes within it and potentially seven AP-2 consensus binding motifs see also Figure 2). This suggests that the gene may contain alternative start sites, and that sequences within exon 1 may also contain promoter activity. Other sequences from which α 1,3 GT promoters can be derived are set forth as SEQ ID NOs:1-6.

All of the references cited herein, including patents, patent applications, and publications, are hereby incorporated in their entireties by reference.

While this invention has been described with an emphasis upon preferred embodiments and illustrative examples, it will be obvious to those of ordinary skill in the art that variations of the preferred embodiments may be used and that it is intended that the invention may be practiced otherwise than as specifically described herein. Accordingly, this invention includes all modifications encompassed within the spirit and scope of the invention as defined by the following claims.

WHAT IS CLAIMED IS:

1. A recombinant expression cassette comprising an α 1-3 galactosyltransferase promoter operably linked to a polynucleotide for expression, other than a polynucleotide encoding α 1-3 galactosyltransferase.
- 5 2. The recombinant expression cassette of claim 1, wherein said promoter is derived from the bovine, porcine, or murine α 1-3 galactosyltransferase genes.
3. The recombinant expression cassette of claim 1 or 2, wherein said promoter comprises any of SEQ ID Nos:1-6.
4. The recombinant expression cassette of any of claims 1-3, wherein said
10 promoter comprises an active derivative of any of SEQ ID Nos:1-6.
5. The recombinant expression cassette of any of claims 1-4, wherein said polynucleotide for expression encodes an antisense RNA molecule or a ribozyme.
6. The recombinant expression cassette of any of claims 1-5, wherein said polynucleotide for expression encodes a protein.
- 15 7. The recombinant expression cassette of claim 6, wherein said protein is a fucosyltransferase, a galactosyltransferase, a β -acetylgalactosaminyltransferase, an N-acetylglycosaminyltransferase, an N-acetylglucosaminyltransferase, a sialyltransferase, or a sulfotransferase.
8. The recombinant expression cassette of claim 6, wherein said protein is a
20 Type I fucosyltransferase, a Type II fucosyltransferase, an α 2-3 sialyltransferase, or an α 2-6 sialyltransferase.
9. The recombinant expression cassette of any of claims 6-8, wherein said polynucleotide for expression is heterogenic to said promoter.
10. The recombinant expression cassette of claim 9, wherein said
25 polynucleotide for expression is human and wherein said promoter is porcine.
11. The recombinant expression cassette of any of claims 6-8, wherein said polynucleotide for expression is a cDNA.
12. The recombinant expression cassette of any of claims 6-8, wherein said polynucleotide for expression is genomic DNA.
- 30 13. A recombinant mutating cassette comprising a first region of homology to an α 1-3 galactosyltransferase genomic sequence adjacent to either a second region of homology to said α 1-3 galactosyltransferase genomic sequence or a polynucleotide for insertion.
14. The recombinant mutating cassette of claim 13, comprising first and
35 second regions of homology to an α 1-3 galactosyltransferase genomic sequence flanking a polynucleotide for insertion.

15. The recombinant mutating cassette of claim 13 or 14, wherein a region of homology is homologous to an exon, an intron, or a promoter of said α 1-3 galactosyltransferase genomic sequence.

16. The recombinant mutating cassette of any of claims 13-15, wherein a
5 region of homology is homologous to all or a portion of any one of SEQ ID NOs: 1-42.

17. The recombinant mutating cassette of any of claims 13-16, wherein said polynucleotide for insertion comprises an expression cassette.

18. The recombinant mutating cassette of claim 17, wherein said
10 expression cassette encodes a marker.

19. A vector comprising the recombinant cassette of any of claims 1-18.

20. The vector of claim 19, which is an oligonucleotide, a plasmid, a cosmid, or a virus.

21. A transgenic cell harboring the vector of claim 19 or 20.

22. A chromosome comprising the recombinant expression cassette of any
15 of claims 1-18.

23. A transgenic cell harboring the chromosome of claim 22.

24. The transgenic cell of claim 23, wherein said α 1-3 galactosyltransferase promoter is native to said cell.

25. The transgenic cell of claim 23 or 24, wherein said polynucleotide for
20 expression displaces a native polynucleotide encoding α 1-3 galactosyltransferase.

26. The transgenic cell of claim 23 or 24, wherein said polynucleotide for expression is cloned between said promoter and a native polynucleotide encoding α 1-3 galactosyltransferase.

27. The transgenic cell of claim 26, wherein said polynucleotide for
25 expression comprises a stop codon.

28. The transgenic cell of any of claims 21, or 23-27, which is an embryonic stem cell, an ovum, a primordial germ cell, a spermatozoon, or a zygote.

29. The transgenic cell of any of claims 21, or 23-27, which expresses said
30 polynucleotide for expression.

30. The cell of claim 29, wherein said polynucleotide for expression encodes a Type I fucosyltransferase, a Type II fucosyltransferase, an α 2-3 sialyltransferase, or an α 2-6 sialyltransferase, and wherein said cell produces said
35 protein.

31. The transgenic cell of any of claims 21 or 23-30, wherein said cell produces a heterogenic complement regulatory protein (CRP).

32. The transgenic cell of claim 31, wherein said CRP is human and wherein said cell is nonhuman.

33. An embryo consisting essentially of transgenic cells according to any of claims 21 or 23-32.

5 34. An organ consisting essentially of transgenic cells according to any of claims 21 or 23-32.

35. The organ of claim 34, which is a lung, a heart, a liver, a pancreas, a stomach, an intestine, a kidney, or skin.

36. A transgenic animal consisting essentially of transgenic cells according to any of claims 21 or 23-32.

37. The transgenic animal of claim 30, which is a cattle, a mouse, a pig, a cat or a dog.

38. A transgenic knockout animal comprising a homozygous disruption in an endogenous α 1-3 galactosyltransferase gene, wherein said disruption prevents the expression of a functional α 1-3 galactosyltransferase protein.

39. The transgenic knockout animal of claim 38, wherein cells isolated from said knockout animal exhibit an increased time of survival in the presence of human serum relative to comparable cells isolated from an animal having a wild type α 1-3 galactosyltransferase gene.

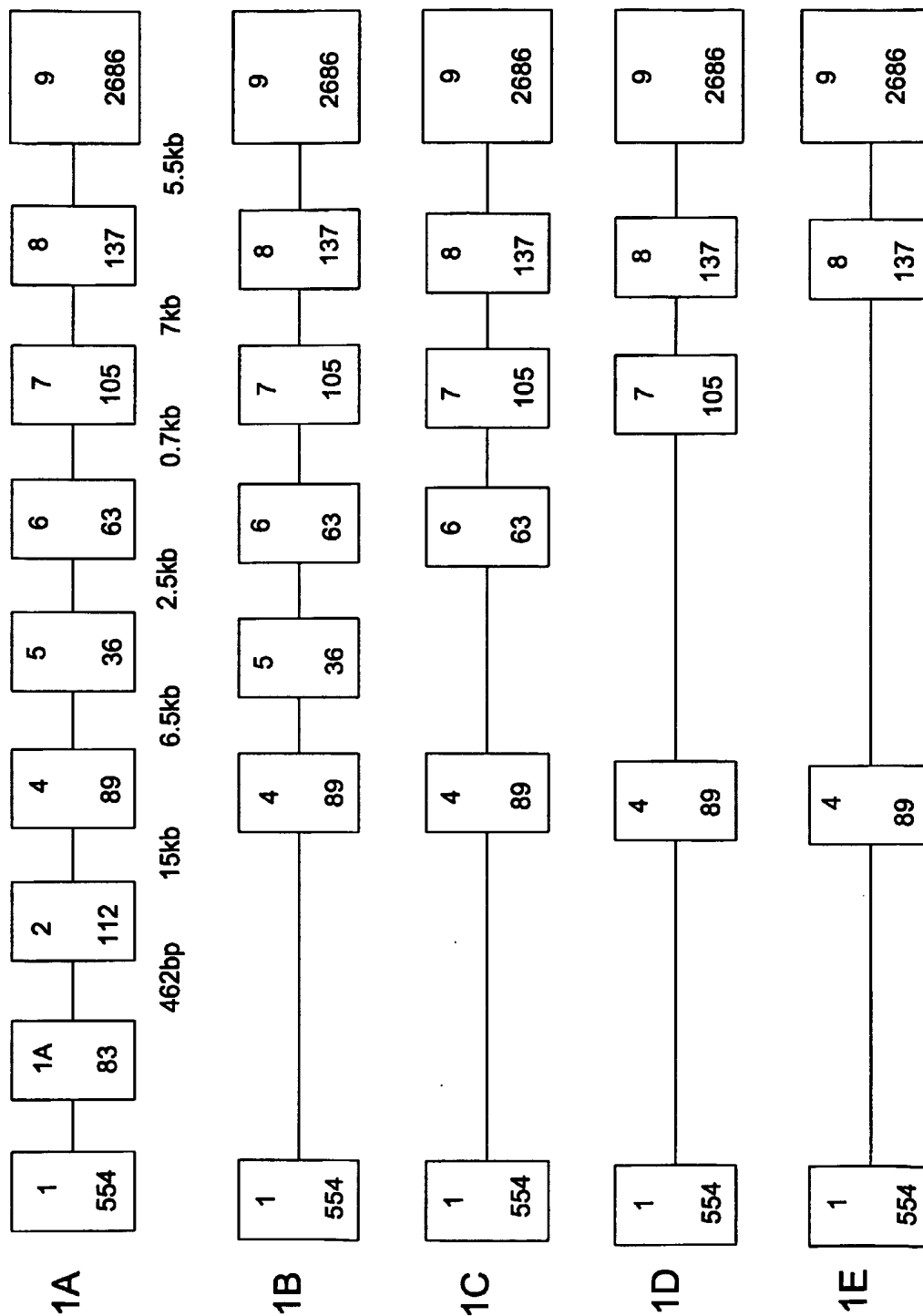
20 40. The transgenic knockout animal of claim 38 or 39, wherein the insertion replaces DNA at the start of the coding region of said α 1-3 galactosyltransferase protein.

41. The transgenic knockout animal of claim 38 or 39, wherein the insertion replaces the promoter of said wild type α 1-3 galactosyltransferase gene.

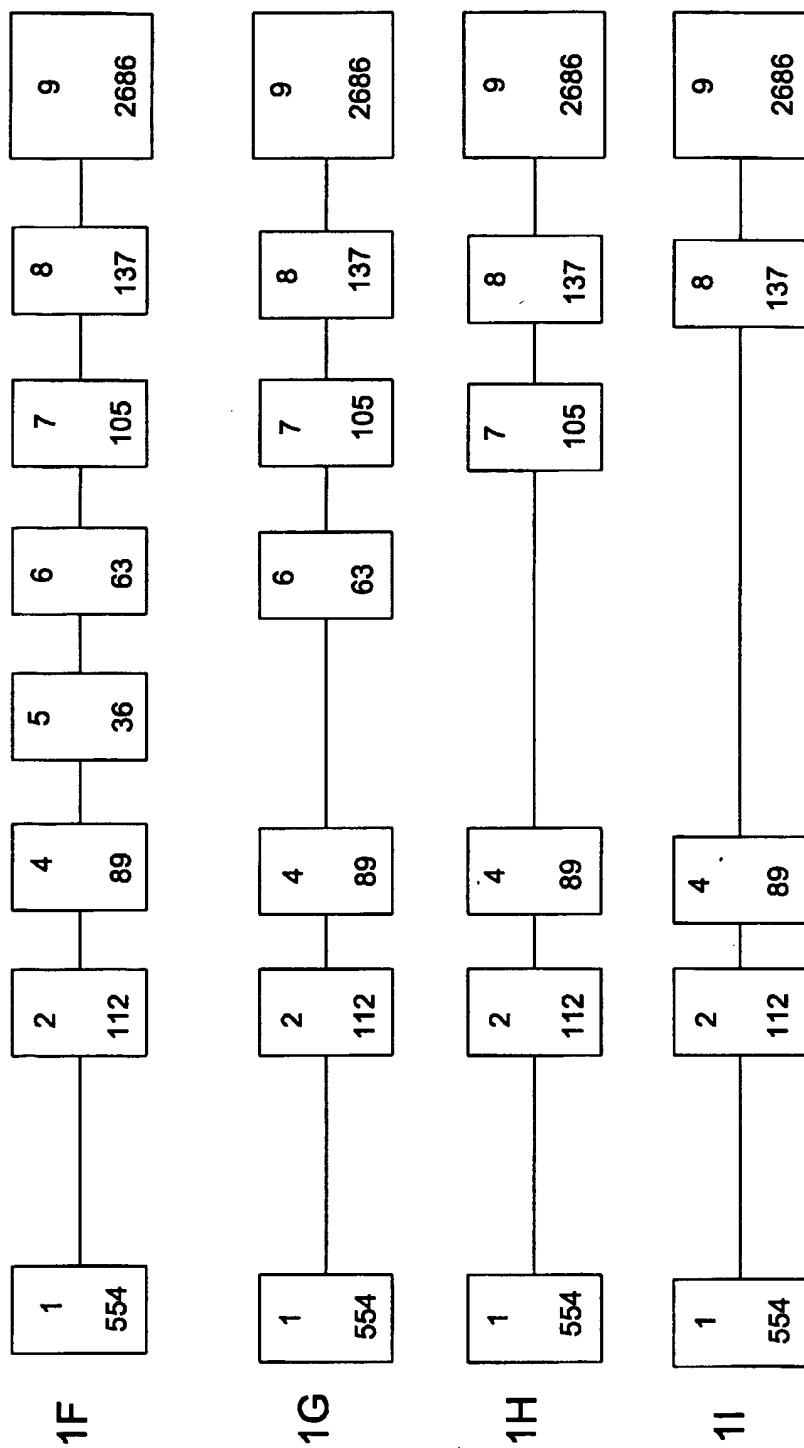
25 42. The transgenic knockout animal of any of claims 38-41, which produces at least one human protein selected from the group of proteins consisting of α 1-3 galactosyltransferase, α (1,2) fucosyltransferase, and complement regulatory proteins.

43. The transgenic knockout animal of any of claim 38-42, which is a pig.

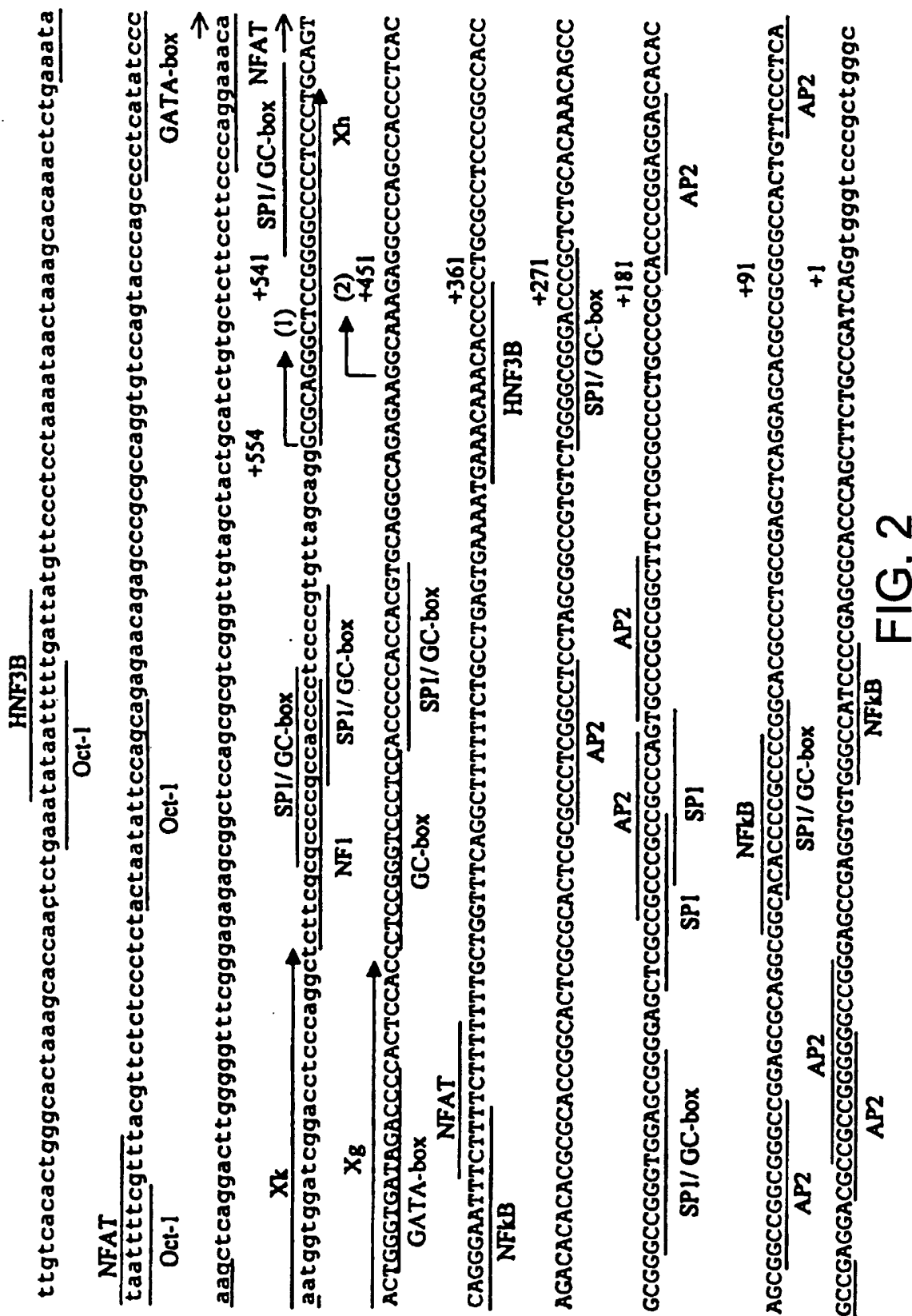
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2 / 4



SUBSTITUTE SHEET (RULE 26)



Schematic genomic organization of human $\alpha 1, 3$ GT gene

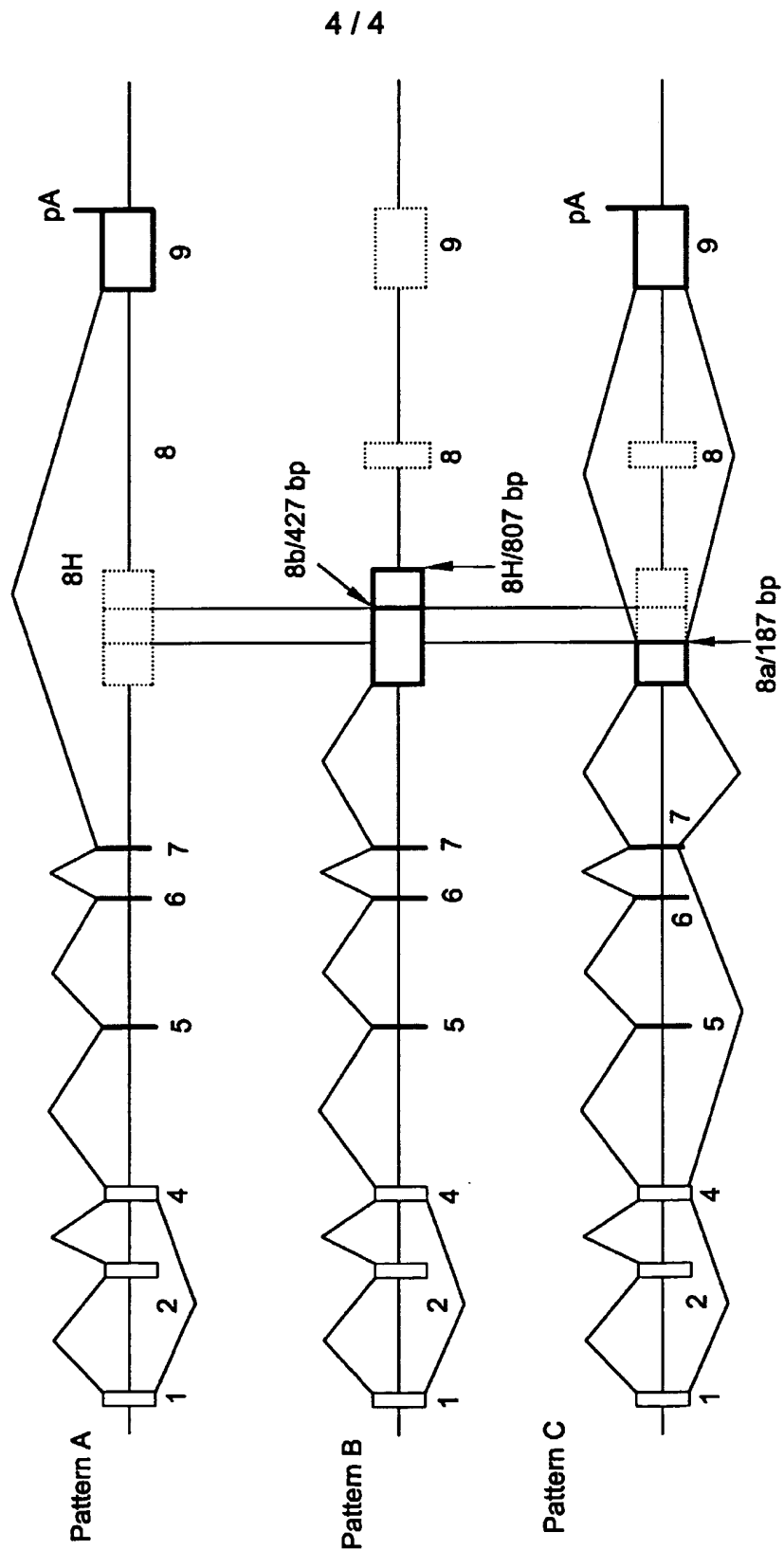


FIG. 3

SEQUENCE LISTING

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Koike, Chihiro

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gtgaggtctc ttccaggtag gaaattgtat tttgggagca ggaggtgggt gtggggaggg 1860
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<210> 4

<211> 820

<212> DNA

<213> Mus musculus

<400> 4

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<211> 501

<212> DNA

<213> bovine

<400> 6

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<210> 7

<211> 3976

<212> DNA

<213> Sus scrofa

<220>

<221> misc_feature

<222> (580)..(580)

<223> "n" is a gap of from about 600 to about 800 nucleotides

<220>

<221> promoter

<222> (1863)..(2992)

<223> fragments and derivatives of this region have promoter activity.

<220>

<221> 5'UTR

<222> (2463)..(3016)

<223> Untranslated exon 1 runs from about nucleotide 2436 to about nucleotide 3016

<220>

<221> Intron

<222> (1)..(2462)

<220>

<221> Intron

<222> (3017)..(3976)

<400> 7

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<211> 8989

<212> DNA

<213> Sus scrofa

<220>

<221> Intron

<222> (1)..(4731)

<220>

<221> misc_feature

<222> (4732)..(4814)

<223> untranslated exon 1A found in some transcripts

<220>

<221> Intron

<222> (4815)..(5241)

<220>

<221> misc_feature

<222> (5242)..(5353)

<223> untranslated exon 2 found in some transcripts

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<221> Intron

<222> (5354)..(8989)

<400> 8

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21

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<210> 9

<211> 240

<212> DNA

<213> Sus scrofa

<220>

<221> Intron

<222> (1)..(29)

<220>

<221> misc_feature

<222> (30)..(118)

<220>

<221> Intron

<222> (119)..(240)

<220>

<221> 5'UTR

<222> (30)..(38)

<220>

<221> misc_feature

<222> (39)..(41)

<223> This "atg" is the translation start codon

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ttctgtcaat gctgcttgtc tcaactgtaa tgggtgtgtt ttgggaatac atcaacaggt 120

aattatgaaa catgatgaaa tgatgttgat gaaagtctcc tctaattctcc tagttatcag 180

ccaagtcacc agcttgcatc aaaagtagga ttactgaca ccgtaaagaa agcattccag 240

<210> 10
<211> 2685
<212> DNA
<213> Sus scrofa

<220>
<221> Intron
<222> (1)..(2140)

<220>
<221> misc_feature
<222> (2141)..(2176)
<223> This region defines exon 5

<220>
<221> Intron
<222> (2177)..(2685)

<400> 10
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tgctaggaag cttagagcaa agtattgtgc ttaaagtctt gcattttcct tggccttcac 120

tttttttaaa acattttttc ttatttaaagt atagctgatt tatagtagcc ttcattctgat 180

atgatttatc ccctggtggt aaatcctggc ttttgttaga tgccatggga tcttggaat 240
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tccaattaga ccctagcct gggaacttcc acatgccgca gggtgcaacc ccaaagata 720
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gcaaagccac cttggacaat aagagctgcc atctattttt tttttcttta aactaagatt 1920

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25

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<210> 11

<211> 180

<212> DNA

<213> Sus scrofa

<220>

<221> Intron

<222> (1)..(37)

<220>

<221> misc_feature

<222> (38)..(100)

<223> This region defines exon 6

<220>

<221> Intron

<222> (101)..(180)

<400> 11

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tctgtgtatc tgctcaaggc tgtagagtcc aaataaaatg gtttcacagc catgaccttc 180

<210> 12

<211> 242

<212> DNA

<213> Sus scrofa

<220>

<221> Intron

<222> (1)..(100)

<220>

<221> misc_feature

<222> (101)..(205)

<223> This region defines exon 7

<220>

<221> Intron

<222> (206)..(242)

<400> 12

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cctccctgcc ttccctcagct tgttttccgt ttgtacgtag gactcacagt taccacgaag 120

aagaagacgc tataggcaac gaaaaggaac aaagaaaaga agacaacaga ggagagcttc 180

cgctagtgga ctggtttaat cctgagtaag aaaagaagcg ttgccctatt tcagtaaadc 240

ca 242

<210> 13

<211> 720

<212> DNA

<213> Sus scrofa

<220>

<221> Intron

<222> (1)..(257)

<220>

<221> misc_feature

<222> (258)..(394)

<223> This region defines exon 8

<220>

<221> Intron

<222> (395)..(720)

<400> 13

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caatgtcaca ccaccagctg actggggcta aaatacagtc aggattcaag gccagtccca	180
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cctcagggtg aggggcttgg gttgcaggga agaaaatctg ctatacccac tgcacccaaa	660
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<210> 14

<211> 2964

<212> DNA

<213> Sus scrofa

<220>

<221> Intron

<222> (1)..(318)

<220>

<221> misc_feature

<222> (319)..(2904)

<223> This region defines exon 9

<220>

<221> terminator

<222> (1010)..(1012)

<223> This is the translation termination signal

<220>

<221> 3'UTR

<222> (1012)..(2964)

<220>

<221> terminator

<222> (2858)..(2863)

<223> This is one transcription termination signal

<220>

<221> terminator

<222> (2883)..(2888)

<223> This is one transcription termination signal

<220>

<221> polyA_signal

<222> (2904)..(2904)

<400> 14

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acagactaga tgataatagc atattgtctc ctctagaaat cccagagggtt acatttacct	300
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<210> 15

<211> 1500

<212> DNA

<213> Sus scrofa

<220>

<221> misc_feature

<222> (1)..(1500)

<223> genomic sequence between exons 2 and 4

<400> 15

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tctgctctct gtggggcact ggaattcag gggatgacaa gaagtcaccc ctctgcctt	180
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cggcaaccta cacacagctc acggcaacgc tggattctta acccactgag caagggcagg 1500

<210> 16

<211> 500

<212> DNA

<213> Sus scrofa

<220>

<221> misc_feature

<222> (1)..(500)

<223> genomic sequence about 4-5 kbp downstream from porcine exon 4.

<400> 16

ggtacccatg aaaagccaa caacacaggc tagaaggagg atgtcagaga gagagagcaa 60
aggaacgtga gagttcaggg agggcaagggt tatgtttggc ttggagatgg atctatgttt 120
tgcatttatt tttttggggg ggggtctttt tgctacttct tgggctgctc ccgaggcata 180
tggagggtcc caggctaggg gtctaattgg agccgcagcc accagcctat gccagagcca 240
cagcaacgca ggatctgagc cacgtctgca accttcacca cagctcacgg caacgccaga 300
tcgttaaccc actgagcaag ggcagggacc gaacctgcaa cctcatggtt cctagtcaga 360

34

ttcgttaagc actgcgccac gacgggaact ccctcattta gaaatattta ttgagcacct 420

actgtatgcc aggcattggt ctaggttcat accaaagaag gctcaaaaag atggcatccg 480

aactgttgcc cttgaaagga 500

<210> 17

<211> 1520

<212> DNA

<213> Mus musculus

<220>

<221> Intron

<222> (1)..(1130)

<220>

<221> promoter

<222> (381)..(1321)

<223> Fragments and derivatives have promoter activity.

<220>

<221> 5'UTR

<222> (1131)..(1320)

<223> untranslated exon 1

<220>

<221> Intron

<222> (1321)..(1520)

<400> 17

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ccatgcttca gtaccaagtt gattctttgc tcttgcctg atgctgaaga cctaaaatga 120

tgaaaatgga aaaagaatga agaataagta tacacacacc cggcctgctt ttgcggatca 180

ggtaggggtccc gccggggcgctc tgacactgaa gccacgcggg ggcttcagtg gggaggagggt 240

gtgggcgagc gcgagcgccg ctattccggc ccagccctac ctcggtcctt gcttttgtcc 300

tggtcactcg atcatttcct ctgtatccac ttctgaactc taggctctgt cccaccctga 360

acagtgtcgc tgcattctgtt tgcttactgg ggtctccgc caccttcctt cgctatccga 420

atagctgata ttcagggcag cacagggcag ggcagggcag ggcagggcga gtagggcaga 480

tcagatcctg ggaccaccgg tactaaccag tgagtgtaga aagcaggagg tgtcttttcc 540

tactgtagtt aggacagggc gggttggctc ttcttatgga caagatggaa aaggggtgca 600

ggtaggggca aagtgtgaga cactcgaatt tgagagacag acagactcct aacagtgaag 660

gaaggaccaa gccaaaatca agcctgggca aagtctcagg cactaacttt gctgtgttgg 720

gtgatgggag gtaatctcgt cacaactttt caaaccacct cgttccctact gcaaggagac 780

accatcaagt gtttgaagat ggcaggggaa cctctcaaca aaacacacac acaaacgttt 840

tattatttta tatttatttt gcatgcaaag tactgtgttt cattatggca tttcataca 900

tatgcgattg caaaaactct tgaaaatcat ccaagaaaca gcaaagcggg aaataatgtt 960

gtgggggggg ggcgcgagg agagagaaca gagactggag agagtgtgt cctccttgct 1020

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gaaggacccc agggactctt atttttgtag ttttgcttgt ctgggccact atcgggccca 1140

gaacagatct gactgcctct ttcattcgcc cggaggtaga taggtgtgtc ttaggaggct 1200

ggagattctg ggtggagccc tagccctgcc ttttcttagc tggctgacac cttcccttgt 1260

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actacgggag tctctgcctt ttgatagtgc ttccttacag ttatTTTTTgg gagtagttgc 1440

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nnnnnnnnnn nnnnnnnnnn 1520

<210> 18

<211> 1207

<212> DNA

<213> Mus musculus

<220>

<221> Intron

<222> (1)..(653)

<220>

<221> 5'UTR

<222> (654)..(773)

<223> untranslated exon 2

<220>

<221> Intron

<222> (774)..(1207)

<400> 18

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ggtatgggtt tctgaggctg tccaagtgc atatggtaaa ggcttctcta tggagattta 180

caccattttc taaagtgcag tgtccacat aactgtgtgg cttccagagc caggctgtgg 240

37

aggaagagct tatctcagaa ccacattttg gcgtcccatc aaagtgcctt gtccgctaac 300

ctgcctctgc cccaggetgt gtcatacgca tctccgggga ggcatcactt gagaatgagt 360

gcatttcaca gggctcccag tttcccttg ggactgggtg atgtggaggg tggtagcctc 420

atcgcttggt actcctggca tggtttggtc ctgcagtttt tcctctgggt gaggaagtca 480

gaggaccaac ccagagccct gattctgcct tgctgcgtag acctgaatca acagccctga 540

taaacagccc atttcccggg gctgaggga caaagcctgt ggctgctgcc gagggatctg 600

tctgccacc ccacccctcc tcttctgaa acagctgttt attattttga caggagtgtg 660

aaccctgtac cttcctttcc tctgtgagc cctgcctcct taggcaggcc agagctcgac 720

agaagctcgg ttgctttgct gtttgctttg gagggaaacac agctgacgat gaggtatggt 780

taaaggattt gtgtctccca gccttgggtc actgcgagct actgttaggt caccaaatgg 840

ttccacctga gggaggacc cttgtctctt ccgaagcttt ccttgggtccc ttctgtgatt 900

tgttgtcctt tcccttttgt ttctgaaaca ggggctggtg gaatgctggc tggggacttt 960

ggtattctgc ttctcttggc agccccggg gctatgccag tcaaggctgc agcctggagt 1020

tctctgtgtg gggtttgggt tggcggggct gagtcttggg cagggcgcgg tgggaggggtg 1080

ctgagctctc tctgctctgg gctgtctcgt acatgtccgt tggctggctg ttcctgggag 1140

gtatcacttg agattgattg cattccacat gacactgctc ccaggacag cccggcactc 1200

nnnnnnn 1207

<210> 19

<211> 900

<212> DNA

<213> Mus musculus

<220>

<221> Intron

<222> (1)..(336)

<220>

<221> misc_feature

<222> (337)..(517)

<223> untranslated exon 3

<220>

<221> Intron

<222> (518)..(900)

<400> 19

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tcaatgtctg ggatccacac ctgatcttct gggatcctcc aaagggttg ggtcacttct 120

ccatctctgc cctctgtagt actctaggct ctagttgact ccactccact gctgctgctg 180

ttcttggtga tcacacctatg gtactggcaa gtaggtgaaa gaagaagagt gaatattcct 240

tcacccaatg tccttatgta ggctccagc agaaggtgtg gctcagatta aaggtgtcta 300

cccccatgcc tggatctaaa acttgctttg ttccaggctg actttgaact caagagatct 360

gcttacccca gtctctgga attaaaggcc tgtactacat ttgcttgac ctaagatttt 420

catgatcact atgcttcaag atctccatgt caacaagatc tccatgtcaa gatccaagtc 480

agaaacaagt cttccatcct caagatctgg atcacagggtg tgcccttctg tttctggatt 540

atagttcatc ccagatgtag tcaagttgac cactaggaat agccatcaca agcccggttg 600

ggaggctgcc ccctgcccc cgccccgcgc gccctgagg ctctcacccc tttcttggtg 660

cagctcttgt cttcatctcc agtgataaac tgcattccc actctgcatc ttgccttct 720
gaacaatcac cgtcccaaag ttcttctcag tcttttgta tcctcttccc tttctttcac 780
aatcttatgc agaatttaaa aaatacctga ctccttcagt agttccagtt gtttgctggc 840
ttgtgggggg ttagtgggg tgaaccaggt ggggctgaaa agtgggtgca nnnnnnnnnn 900

<210> 20

<211> 1020

<212> DNA

<213> Mus musculus

<220>

<221> Intron

<222> (1)..(479)

<220>

<221> misc_feature

<222> (480)..(568)

<220>

<221> 5'UTR

<222> (480)..(489)

<220>

<221> misc_feature

<222> (490)..(492)

<223> This "atg" is the translation initiation codon

<220>

<221> Intron

<222> (569)..(1020)

<400> 20

40

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gacacttgct gctgagttag ttacaaatgt atcctgttag gaaggatgtg ggcagatgcc 180
tttcattatc tttactgcat caaacatttt atgggtatga gtgttttgcc tgcaagtatg 240
tatatgtacc acttgatat gtggacccca tggaggccag aagagcatca ggtcctgtga 300
aaccagagtt atggacacct gtgagctgca aatgtggatg ctgggaactg aatcgagcag 360
gtgtttcatt gaggtgtttc aaccacacag ctgtttctcc agccccagaa gccatctctc 420
attccagatt tagtttattt aatctatttc cccctctttt tttctccctg cctctacagg 480
agaaaataat gaatgtcaag ggaaaagtaa tcctgttgat gctgattgtc tcaaccgtgg 540
ttgtcgtggt ttgggaatat gtcaacaggt aattatgaag ccagctagaa aggctgcttt 600
cattccctgt gactggtgcc agctgagtga ccaatcagtc tgaacataag ggacggagcc 660
gtgagcagga gtccagtctt cctgtgttcc tgagccccag atggccatta aaactgtaga 720
ccatccaagt cacttctgcc ttagtaatta tcctctttca tgccgtgctc ctcaaacctc 780
gaatttctgt aagctagatg gagagagaaa gtacattaag ccaaaccac catctcaagt 840
aatttgata agcagatccc agaagattca ggccaggcag ggtagtgcat gtatggagtc 900
cttgtgcttg caaggcagag gcaggagcat catacaaatg gaagaccaag cttgtcttca 960
tagtgacttc caggccagct gtagccttac aaggagaccc nnnnnnnnnn nnnnnnnnnn 1020

<210> 21

<211> 1020

<212> DNA

<213> Mus musculus

<220>

<221> Intron

<222> (1)..(584)

<220>

<221> misc_feature

<222> (585)..(620)

<223> exon 5

<220>

<221> Intron

<222> (621)..(1020)

<400> 21

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gctgtatgtt gccttctctg ttacattgta tatttttcat gagccccagc actcgggtgtg 120

taggacttgc ctagcacgtg taagactgat gagagctagt gccctaaagt agttgtagct 180

ggcctagcct tctggttaaa gcaacaccca tgggggctgc tcagaagaag ggatctgagc 240

tgaatgtggc ggctatttcc tgtggggaag aatcctcagc ctgaggtggc tggccgtggc 300

gcttcacct tccccgcctt cctcattgcc cagcttctgg gactgtggtg gaagaggacc 360

ttcctgtcat gtaacaaaca gctgggtgac tttaaaagag agaaagaggg aaaaaaatcc 420

cccaaataaa aacaagaatt gagagtgttt gggtgccac ttctgttcct cagtgatgct 480

tgtgggaatc ccctgagaac ccaaacgctt aaggaaaacc actgcagtga agcctttctg 540

agaattaaaa gtatatgacg tttctatttc ttatttgtcc ttagcccaga cggctctttc 600

ttgtggatat atcacacaaa gtaagtgttc tgaattctgt gtatctattg gatgtctgga 660

tcacttgatt tttttttttt agcccctaaa gttgatttcc tctcttcaag ccagccaatg 720
tagtgctcgg gccacagtaa agggaggaga gaggccagga caggaggag gattgctagg 780
gccctggggg cagggtgca actctgctag tccccaaact ggtctttgta gaatagtgat 840
gagttttgct ctcggttctg ctcaaggagac tctcctcaaa tattgtcatg gggaccattt 900
ttgggtgacg tagggaaaga gcccaggga ctgcatgctg tagtgtgtac ctcagtgc 960
gctgtgaggc actgaggag gacttacgtt cagttccagt nnnnnnnnnn nnnnnnnnnn 1020

<210> 22
<211> 1020
<212> DNA
<213> Mus musculus

<220>
<221> Intron
<222> (1)..(595)

<220>
<221> misc_feature
<222> (596)..(661)
<223> exon 6

<220>
<221> Intron
<222> (662)..(1020)

<400> 22
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aatacatgca tgtatacaga cacacacaga cacacacgca tgcagtcatt ctcggaagg 120

43

tgctttttct tattttaata ttacccctcg ttacagccgc tttatgttca ccaggctctt 180
gcatactgc tgtctcattg gtcattacag atcccttcgt ggacggatta ttattgatta 240
ccctcttcag agaagaacgt ggcaagtttag acagtgtgag tgtatgcaa agtcaactcca 300
ctagcaggag gagatcgtga ccacaggctc tcagatctgc agggctctcca ccattctgat 360
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aagggcgag ctgaggcccc tcaagtccac tctctgcctt tagctcagct gccttttgcg 480
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aagttcagga ccgcctcgat ttctagatgt gtttatattc ttttccattt cctagaattc 600
cagaggttg tgagaacaga tggcagaagg actggtggtt cccaagctgg tttaaaaatg 660
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tcaggaggca attctgcctt tccagtacgg gttccagtgt gtgatcacca gactcagatg 960
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<210> 23

<211> 912

<212> DNA

<213> Mus musculus

<220>

<221> Intron

<222> (1) .. (389)

<220>

<221> misc_feature

<222> (390) .. (491)

<223> exon 7

<220>

<221> Intron

<222> (492) .. (912)

<400> 23

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gaaatgtccc ttggagtact gttctgaaac atctcaccga cttctgaaat aactgagggt 180

tacagggtca ctggaacctc agcccctgac ccacatggtg gccagagagg caaatgctgt 240

accttttatc agaagtgtgt agggatcaag gggtcagtgc cctgagtcct ccagtccacc 300

cagtgggtgtg agtgatecct tctttccctt gagacacgag tcatggaagc cacctgtcct 360

taccaacttt gtcctacctt tgtccacagg acccacagtt atcaagaaga caacgtagaa 420

ggacggagag aaaagggtag aaatggagat cgcattgaag agcctcagct atgggactgg 480

ttcaatccaa agtaaggacg gacaggagat tgggggtggg ggtgctgagt ggggttctga 540

ggagatgctg aggggagtgct tgaggggggtg ccggcaggag ggggtgctgg caggagaggg 600

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tggttaattgc agcaggaaat ggccagtggg aggttaaaca taaacactgg gtgttaagga 840

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nnnnnnnnnn nn 912

<210> 24

<211> 608

<212> DNA

<213> Mus musculus

<220>

<221> Intron

<222> (1)..(221)

<220>

<221> misc_feature

<222> (222)..(359)

<223> exon 8

<220>

<221> Intron

<222> (360)..(608)

<400> 24

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caagattcag tgacagtcac tggcctccct tccttggccca gtctctcacc acacctcagt 180

gtaatgcttc tgactcgggtg ttgcatgctt cttctcacca ggaaccgccc ggatgttttg 240

acagtgaccc cgtggaaggc gccgattgtg tgggaaggca cttatgacac agctctgctg 300

46

gaaaagtact acgccacaca gaaactcact gtggggctga cagtgtttgc tgtgggaaag 360
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gtgtggggct ccagggcccc acaaaggctg gaatttgaca gtagacttcc cccttctttc 480
ttataatggc tgagaaaaaa caatgatagt aggtgatgag gtatttctct gccagtgagt 540
gagccaatcc aagccagagt agattgtatt aaatacaggt ttattgggaa gctgctctca 600
nnnnnnnn 608

<210> 25

<211> 3240

<212> DNA

<213> Mus musculus

<220>

<221> Intron

<222> (1)..(369)

<220>

<221> misc_feature

<222> (370)..(3010)

<223> exon 9

<220>

<221> terminator

<222> (1088)..(1090)

<220>

<221> 3'UTR

<222> (1091)..(3010)

<220>

<221> Intron

<222> (3011)..(3240)

<400> 25

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acaccgagct ctcaagtgtg caggcatcga agagcacgcg gtcggggctg tgcacccca	180
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ccagctagtg tcgagtggta tgtggagaag ccatcccctc ctaacataca atacagatca	300
tctactgtaa tgttaagtat ggtattacat gtatatatgt acccatatat aagtgtgata	360
gtccgtggtg gttcaatgta gccctctcta tttcaggtag attgagcatt acttagaaga	420
ctttctggag tctgctgaca tgtacttcat gggtggccat cgggtcatat tttacgtcat	480
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acaagtagca acacttgatt tcaactttta aaagaaacaa tcaaaaccaa aaccactac 1200

catggcaaac agatgatttc tcctgacacc ttgagcctgt aatatgtgag aaagagtcta 1260

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cttgattcta gaaatcaaaa ttaatttgac aaaggaaaag cagatgccgg aaacttcttc 1380

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gaggaccagc accctattat atcagaagac aatctctcat catcaggtcc tacctacaac 1980

ctgctctgaa cctccgagtt cctcagccca tcgtgttcca gtgtgggggc ctgtatggag 2040

caggtgactg aagacaaagc cccctgtcac atgacctcat ttcccctgct ctagtactat 2100

gcaagtgtga cagccagcca gccagatgta ctggacaaca taggaaccca ctttatggca 2160

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tgcaggagcc cctgtatagg tggttctcaa cctatgggtc gcgacccctt tgggaagtgt 2280

taaatgaccc ttccacaggt gtcccctaag acggttaaaa aacatagata ttccactct 2340

gactggtaac agtagcagaa ttacagttat gaaatagcaa gggaaataat tctgggggtc 2400

gtgtcatcca taccatgagg agctacatta ggtcacatca ttagggaagt tgagaagcat 2460

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53

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59

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66

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73

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<222> (61)..(176)

<223> human untranslated exon 7

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<221> Intron

<222> (177)..(242)

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<400> 42
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ttcagatata atgatcatta cttggaggag ttcataacat ctgctaatag gtacttcatg 120

gttggccaca aagtcattt ttacatcatg gtggatgatg tctccaagct gccgtttata 180

gagctgggtc ctctgcattc cttcaaaatg tttgagggtca agccagagaa gaggtggcaa 240

gacatcagca tgatgcgtat gaagatcact ggggagcaca tcttggcca catccaacac 300

gaggtcgact tcctcttctg catggatgtg gaccagggtct tccaagacca ttttggggtg 360

gagaccctag gccagtcagt ggctcagcta caggctggcg gtacaaggca gatccctatg 420

actttaccta ggagaggtgg aaagagtcag caggatacat tccatttggc caggggattt 480

ttattaccat gcagccattt ctggaggaac acccattcag gttctcaaca tcaccagga 540

gtgctttaag ggaatcctcc tggacaagaa aaatgacata gaagccaagt ggcatgatga 600

aagccaccta aacaagtatt tccttctcaa taaaccctct aaaatcttat ccctaaaata 660

ctgctgggat tatcatatag gcctgccttc agatattaaa actgtcaagt gatcgtggca 720

gacaaaagag tataatttgg ttagaaataa tgtctgactt caaattgtgc cagtagattt 780

ctgaatttaa gagagagaat attctggcta cttcctcaga aaagtaacac ttaattttaa 840

cttcaaaaaa tactaatgaa acaccaacag ggcaaaaaca taccattcct ccttgtaact 900

tggggctttg taatgtggaa gaatgaatct agggcaatca gatataaatt cccagtgatt 960

tcttatctat tctgggtttg ggggaaatac tatcaactga accaaaaata acttgtcata 1020

ggcagagata aagccagaaa cactctacac atgccagatg acatctggag aaaagggtgc 1080

taagggaagc gtttggcagc aagatatgat tgtaaggggt tgtcccttga gttcaatgtc 1140

tgctatttc tgatgggtct aaagcaacat ggagttactg tgcagcagaa ctctcagtaa 1200

agacaccatt tgccttggca atcctcaaaa agcttcaata gcagattgct tcagaccatc 1260

tgtagtccgt ccttttctca tctggatgtt gtttggcttc tgtgcgaaag attggtggag 1320

tgtcccagta gatatcatgg tgggtgtgtga tcagagtccc aaggaacctg aatgagccaa 1380

ggtgcccagc atgaagtcaa aacaaagcct tgacatgagt ttgcatgaa atagcgaaga 1440

gagagtggaa gagaggagcc aatcactgtg gggcagtgcc accctgaggg cacttagggg 1500

atggggtttg tgcttaaata catcacagat ccaggtactg aatgggagga agtgtgggtg 1560

atttccaatc tcattgacct tatgttcagg gacttgaacg gaagatgttt cttgtgttgc 1620

ctaagtggta ttcagtctac cagactctgc aacttgcac ttcaaatacct tggtaaagag 1680

atgtggatgg tgcagagaa ggcaaaggcc tgcagtggat tgaagaggct tgcaagcagt 1740

tctgtttcta ggatgtgggc ttcacagaa gacactcggc caccacttag ctagtctaaa 1800

cctcagggtt cctcagocca tcatacccca acttgaggga ctgacatcaa ggagtagact 1860

ggagaaacag ccctcccatc aagtaacctc ttgttctctc ctgctccatc tgactatag 1920

aagtgtaata attagacata cttggcaaaa tggctaattg atttggtaac agaagcatga 1980

gccataacaa tggaagatct agttatcatg actgaacagc ttaacattca attcccttct 2040

ctaagagaag ctgtgaaatc ctacatatta tttaaagtta accaaatcaa tgtaaaggga 2100

gttaggagac agtgtgtacc tatgcacgta tatttatgtt ttgcttgtgt tccagtctcg 2160

gtcatttgtt tccattttca agcaatttat ttgaagagcc attgcactag cctgatgtat 2220

actgcaatga gcttctttga taaaatgaaa cttaaatttt tctcgaccat ttcaccgtgc 2280

ctcctacttc attttttgcc agaaaatctc acatccaaca aaacaaaaca aaaaccctga 2340

attagtgggc tttgaaaagg aaaaagcagg gctttgaaaa agtagatcac acatcagtta 2400
agactcctgc ttctctatta gtcaggttgt cttggattca gtctggagta ggcagagctt 2460
aagggttttt aagtcctgac ccaaagaaat gatctagcct gaaagtttag agcaaaggac 2520
taatgtttac ttttaaagga atttcttgat ttttttaaaa aacttcatta aagttttaa 2580
ccccaatgga caaattcata atcttggttaa tcgttattac taaacttttt aaaaaatgtc 2640
ccaatttaca attaaataaa ttactttctc agtatattct ggtctggtca tggattgtgc 2700
atttctccc aaagatatcc aaaattgtca attagagaat tttaggtttt cagactcaga 2760
aaagtcctca cgcccttctg aaaatgtgtc cactattaca gaaatagaac agacttgga 2820
ttcccaaatt tttgtttgtt tttnnnnn 2848

<210> 43
<211> 2303
<212> DNA
<213> Rhesus monkey

<220>
<221> misc_feature
<222> (1)..(44)
<223> This is exon 1

<220>
<221> misc_feature
<222> (45)..(159)
<223> This is exon 2

<220>
<221> misc_feature

<222> (160)..(278)
<223> This is exon 3

<220>
<221> misc_feature
<222> (279)..(367)
<223> This is exon 4

<220>
<221> misc_feature
<222> (368)..(403)
<223> This is exon 5

<220>
<221> misc_feature
<222> (404)..(469)
<223> This is exon 6

<220>
<221> misc_feature
<222> (470)..(584)
<223> This is exon 7

<220>
<221> misc_feature
<222> (585)..(2260)
<223> This is exon 9

<220>
<221> misc_feature
<222> (543)..(545)
<223> This is an early stop codon

<220>
<221> misc_feature
<222> (1276)..(1278)
<223> This is a stop codon

<220>
<221> misc_feature
<222> (1225)..(1260)
<223> This is a polyadenylation signal

<400> 43
gctcgctgcg cgccggctcct ggggtgccagg gttctgcgga tcaggagttg aaaccagcat 60

cttcccttca tctgagtcct gcctccttct gcagaaggga gctcaaaaga actttgttgt 120

tttgctttt actctggggt gaaagcaaca gacgataagg atctcactct gtcgccaag 180

ctggagtgca gtggcttgat tacagctcac tgtagcctgg accttccaag gctctgggtg 240

atcttcttac ctcagcttcc ccagtagctg gactacagga gaaaataatg aatgtcaaag 300

gaaaagtaat tctgtcaatg ctggttgtct caactgtgat cattgtgttt tgggaatata 360

tcaatagccc agaaggttct ttcttgggga tgtatcgctc aaaaaccga gaggttgatg 420

acagcagtgc tcagaagagc tgggtggttc cgagctggtt taacaatggg atccacaatc 480

atcaacaaga ggaagaagac atagacaaaa aagaggaaga gaggagacca aagaaaggaa 540

gatgacacaa cagagcttcg gctatgggac tgatttaatc caaaatatat tgagcattac 600

ttggaagagt tcataacacc tgctaatagg tacttcaagg tcggccacaa agtcatatatt 660

tacattatag tggatgatgt ctccaagggtg ctgtttatag agctgggtcc tctgcattcc 720

ttaaaagtgt ttgaggtcaa gccagagaag aggtggcaac acatcagcat gatgcctgtg 780

aagatcatca gggagcacat cttggccac atccaacacg aggtcgactt cctcttctgc 840

atggatgtag accaggtctt ccaagacaat tttggggtga agaccctagg tcagtcagtg 900

gctcagctac agccctggtg gtacaaggca gatcctgatg actttaccta ggagaggcag 960

aaagagtcag cagcatgcat tccatttggc caggaggatt tttattacca cacagccatt 1020

tttggaggaa caccatttca ggttctcaac atccccagg agtgctttaa gagaatcctc 1080

ctggaaaaga aaaatgacat agaagctgag tggcatgatg aaagccacct aaaccagtat 1140

ttccttctca acaaaccctc taaaatctta tccctagaat actgctggga ttatcatatc 1200

agcctgcctt cagatattaa aactgtcaag cggctgtggc agacaaaaga gtataatttg 1260

gtagaaata tcacttgact tcaaattgtg ccagtagatt tctgaatttg agagaggagt 1320

attctggctg ctctctcaga aaagtaacac ttaattttta gttaaaaaaa atactaatga 1380

aacaccaaca tggcaaacac ataccattcc ttcttgtaac ttgaggcttt gtaatgtggg 1440

agaatgaatc tagggtaatc agatgtaa tcccagtgat ttcttatcta ttttgggttt 1500

gggggaaata ctatcaactg aacaaaaaag aacttgtcat aggcaaagat aaagccagaa 1560

acactctaca catgccacat aacatctgga gaaaagggtg ctaagggaag cgtttggcag 1620

caagatatga ttgtaagggg ttgtcccttg agttcaatgc ctgcctatct ccaatggatc 1680

taaaacaacg tgaagttact gtgcagcaga gctctcagta aggacaccat ttgccttggc 1740

aatcctcaaa attcttcaat agcagattgt ttcaggccat ctgtagtctg tccttttctc 1800

atcaggatgt tgtttggctt ctgtgcgaaa aattggtgga gtgtcctggt agatattgaa 1860

actaggcctc atatagaaaa aattaacacc aggtggctct ggatagagtc ccgccctgcc 1920
tcgatgagga cccaccctga taggggtcca ccctgccaat tccgagaaac aacctcatgg 1980
gggtccaccc tgccaattcc ggggggtcca ccctgcctcg aagttcccgg aatcaacaac 2040
tccaggaaaa aacctcataa ggtcctgctc taaccaatta gcataagacg ccttgctcag 2100
gccatagcta gacccaatca ttttgcgctt taagctttgt ttgaatttcg cggcctaagc 2160
tgtgtttgaa cttgtgtttg cctatataaa cagcctgtaa caagcagtcg ggggtcccagg 2220
gccaaacttag agcttgggac cctagcgcgc tagtaataaa taactctctg ctgcgaaaaa 2280
aaaaaaaaa aaaaaaaaaa aaa 2303

<210> 44

<211> 2630

<212> DNA

<213> Rhesus monkey

<220>

<221> misc_feature

<222> (1)..(44)

<223> This is exon 1

<220>

<221> misc_feature

<222> (45)..(159)

<223> This is exon 2

<220>

<221> misc_feature

<222> (160)..(278)

<223> This is exon 3

<220>

<221> misc_feature

<222> (279)..(367)

<223> This is exon 4

<220>

<221> misc_feature

<222> (368)..(403)

<223> This is exon 5

<220>

<221> misc_feature

<222> (404)..(469)

<223> This is exon 6

<220>

<221> misc_feature

<222> (470)..(584)

<223> This is exon 7

<220>

<221> misc_feature

<222> (585)..(911)

<223> This is exon 8

<220>

<221> misc_feature

<222> (912)..(2587)

<223> This is exon 9

<220>

<221> misc_feature

<222> (288)..(290)

<223> This is a putative start codon

<220>

<221> misc_feature

<222> (543)..(545)

<223> This is a putative stop codon

<220>

<221> misc_feature

<222> (1603)..(1605)

<223> This is a putative stop codon

<220>

<221> misc_feature

<222> (2582)..(2587)

<223> polyadenylation signal

<400> 44

gctcgctgcg cgccggctct gggtgccagg gttctgcgga tcaggagttg aaaccagcat 60

cttcccttca tctgagtcct gcctccttct gcagaaggga gctcaaaaga actttgttgt 120

tttgctttt actctggggt gaaagcaaca gacgataagg atctcactct gtcgccaag 180

ctggagtgca gtggcttgat tacagctcac tgtagcctgg accttccaag gctctgggtg 240

atcttcttac ctgagcttcc ccagtagctg gactacagga gaaaataatg aatgtcaaag 300

gaaaagtaat tctgtcaatg ctggttgtct caactgtgat cattgtgttt tgggaatata 360

tcaatagccc agaaggttct ttcttgggga tgtatcgctc aaaaaacca gaggttgatg 420

acagcagtgc tcagaagagc tgggtggttc cgagctggtt taacaatggg atccacaatc 480

atcaacaaga ggaagaagac atagacaaaa aagaggaaga gaggagacca aagaaaggaa 540

gatgacacaa cagagcttcg gctatgggac tgatttaatc caaagaaacg cccagaggtg 600

gtgagagtga ccagatggaa ggcaccggtt gtgtggaaag gcacttaca caaagccatc 660

ctaggaaatt attatgccaa acagaaaatt acggtgggat tgaaggcttt tgctattgga 720

agtgggtgtc actgatgaaa ctgtccttga ctatttcttg ttccactgtc aagacatttt 780

tgtggagact cctgaactga tggaggccag ccatgatatt ttgatttatt agatagaaga 840

atgttttcat ggaactgttt tagtctcctt tctgctgagg ccctaaaatg ctgagaacaa 900

aataagagta gatatatgta gcattacttg gaagagttca taacacctgc taatagggtac 960

ttcaaggtcg gccacaaagt catattttac attatagtgg atgatgtctc caaggtgctg 1020

tttatagagc tgggtcctct gcattcctta aaagtgtttg aggtcaagcc agagaagagg 1080

tggcaacaca tcagcatgat gcctgtgaag atcatcaggg agcacatctt ggccccatc 1140

caacacgagg tcgacttcct cttctgcatg gatgtagacc aggtcttcca agacaatttt 1200

ggggtgaaga ccctaggtca gtcatgggt cagctacagc cctggtggta caaggcagat 1260

cctgatgact ttacctagga gaggcagaaa ggtcagcag catgcattcc atttggccag 1320

gaggattttt attaccacac agccattttt ggaggaacac ccattcaggt tctcaacatc 1380

cccaggagt gctttaagag aatcctcctg gaaaagaaaa atgacataga agctgagtgg 1440

catgatgaaa gccacctaaa ccagtatttc cttctcaaca aaccctctaa aatcttatcc 1500

ctagaatact gctgggatta tcatatcagc ctgccttcag atattaaaac tgtcaagcgg 1560

tcgtggcaga caaaagagta taatttggtt agaaatatca tctgacttca aattgtgccca 1620

gtagatttct gaatttgaga gaggagtatt ctggctgctt cctcagaaaa gtaacactta 1680

attttaagtt aaaaaaata ctaatgaaac accaacatgg caaacacata ccattccttc 1740

ttgtaacttg aggctttgta atgtgggaga atgaatctag ggtaatcaga tgtaaatcc 1800

cagtgatttc ttatctatct tgggtttggg ggaaatacta tcaactgaac caaaaagaac 1860

ttgtcatagg caaagataaa gccagaaaca ctctacacat gccacataac atctggagaa 1920

aagggtgcta agggaagcgt ttggcagcaa gatatgattg taaggggttg tcccttgagt 1980

tcaatgcctg cctatttcca atggatctaa aacaacgtga agttactgtg cagcagagct 2040

ctcagtaagg acaccatttg ccttgccaat cctcaaaatt cttcaatagc agattgtttc 2100

aggccatctg tagtctgtcc tttctcatc aggatgttgt ttggcttctg tgcgaaaaat 2160

tggtggagtg tcctggtaga tattgaaact aggccata tagaaaaaat taacaccagg 2220

tggtctgga tagagtcccg ccctgcctcg atgaggaccc accctgatag ggtcccaccc 2280

tgccaattcc gagaaacaac ctcatggggc cccaccctgc caattccggg ggtcccaccc 2340

tgctcgaag ttcccgaat caacaactcc aggaaaaaac ctcataaggt cctgctctaa 2400

ccaattagca taagacgcct tgctcaggcc atagctagac ccaatcattt tgcgccttaa 2460

gctttgtttg aatttcgctg cctaagctgt gtttgaactt gtgtttgcct atataaacag 2520

cctgtaacaa gcagtcgggg tcccagggcc aacttagagc ttgggaccct agcgcgctag 2580

taataaataa ctctctgctg cgaaaaaaaa aaaaaaaaaa aaaaaaaaaa 2630

<210> 45
<211> 35
<212> DNA
<213> Artificial/Unknown

<220>
<221> misc_feature
<222> ()..()
<223> Antisense primer for cloning porcine exon 4

<400> 45
ctgttgatgt attoccaaaa cacaaccatt acagt

35

<210> 46
<211> 27
<212> DNA
<213> artificial sequence

<220>
<221> misc_feature
<222> ()..()
<223> Antisense primer for cloning porcine exon 4

<400> 46
agacaagcag cattgacaga accactc

27

<210> 47
<211> 25
<212> DNA
<213> artificial sequence

<220>
<221> misc_feature

<222> ()..()

<223> Antisense primer for cloning porcine exon 2

<400> 47

ctcatcctct gcttctctcc cccca

25

<210> 48

<211> 26

<212> DNA

<213> artificial sequence

<400> 48

ccccccagag taaaaggcga aacaag

26

<210> 49

<211> 25

<212> DNA

<213> artificial sequence

<220>

<221> misc_feature

<222> ()..()

<223> Sense primer for cloning porcine exon 2

<400> 49

aacgcagcac cttcccttcc tccca

25

<210> 50

<211> 25

<212> DNA

<213> artificial sequence

<400> 50

93

cttgtttcgc cttttactct ggggg

25

<210> 51

<211> 23

<212> DNA

<213> artificial sequence

<220>

<221> misc_feature

<222> ()..()

<223> Sense primer for cloning porcine exon 1

<400> 51

gccactgttc' cctcagccga gga

23

<210> 52

<211> 24

<212> DNA

<213> artificial sequence

<220>

<221> misc_feature

<222> ()..()

<223> Sense primer for cloning porcine exon 1

<400> 52

cgagcgcacc cagcttctgc cgat

24

<210> 53

<211> 24

<212> DNA

<213> artificial sequence

<220>
<221> misc_feature
<222> ()..()
<223> Antisense primer for cloning porcine exon 1

<400> 53
tgcgctcggg gatggcctc tcct 24

<210> 54
<211> 24
<212> DNA
<213> artificial sequence

<220>
<221> misc_feature
<222> ()..()
<223> Antisense primer for cloning porcine exon 1

<400> 54
ggcgtcctcg gctgaggga cagt 24

<210> 55
<211> 28
<212> DNA
<213> artificial sequence

<220>
<221> misc_feature
<222> ()..()
<223> Sense primer for cloning porcine exon 1A

<400> 55
cagaacaact tctgaagcct aaaggatg 28

<210> 56
<211> 27
<212> DNA
<213> artificial sequence

<220>
<221> misc_feature
<222> ()..()
<223> Sense primer for cloning porcine exon 1

<400> 56
caaatggtgg atcggacctc ccaggct

27

<210> 57
<211> 27
<212> DNA
<213> artificial sequence

<220>
<221> misc_feature
<222> ()..()
<223> Sense primer for cloning porcine exon 1

<400> 57
agtactgggt gatagacccc actccac

27

<210> 58
<211> 25
<212> DNA
<213> artificial sequence

<220>

96

<221> misc_feature
<222> ()..()
<223> Sense primer for cloning porcine exon 1

<400> 58
gcgcagggct ccggggcccc tcct 25

<210> 59
<211> 27
<212> DNA
<213> artificial sequence

<220>
<221> misc_feature
<222> ()..()
<223> Sense primer for cloning porcine exon 9

<400> 59
ctgggattat catataggca tgtctgt 27

<210> 60
<211> 27
<212> DNA
<213> artificial sequence

<220>
<221> misc_feature
<222> ()..()
<223> Sense primer for cloning porcine exon 9

<400> 60
agagtattac tctggctact tctccag 27

<210> 61
<211> 27
<212> DNA
<213> artificial sequence

<220>
<221> misc_feature
<222> ()..()
<223> primer for identifying 5' flanking region of murine exon 1

<400> 61
ctgagagcgc gaggtcttca gcagaat

27

<210> 62
<211> 28
<212> DNA
<213> artificial sequence

<220>
<221> misc_feature
<222> ()..()
<223> primer for identifying 5' flanking region of murine exon 1

<400> 62
cttctcattc caagaagagt cttacaag

28

<210> 63
<211> 27
<212> DNA
<213> artificial sequence

<220>
<221> misc_feature

<222> ()..()

<223> primer for identifying 3' flanking region of murine exon 1

<400> 63

cctgcctttt cttagctggc tgacacc

27

<210> 64

<211> 27

<212> DNA

<213> artificial sequence

<220>

<221> misc_feature

<222> ()..()

<223> primer for identifying 3' flanking region of murine exon 1

<400> 64

cttgtagact cttcttgga tgagaag

27

<210> 65

<211> 27

<212> DNA

<213> artificial sequence

<220>

<221> misc_feature

<222> ()..()

<223> primer for identifying 5' flanking region of murine exon 2

<400> 65

catcgtcagc tgtgttcct ccaaagc

27

<210> 66
<211> 27
<212> DNA
<213> artificial sequence

<220>
<221> misc_feature
<222> ()..()
<223> primer for identifying 5' flanking region of murine exon 2

<400> 66
aaagcaaccg agcttctgtc gagctct

27

<210> 67
<211> 38
<212> DNA
<213> artificial sequence

<220>
<221> misc_feature
<222> ()..()
<223> primer for identifying murine exons 2 and 3

<400> 67
gtaccttctt ttctctgtc gagccctgcc tccttcgg

38

<210> 68
<211> 35
<212> DNA
<213> artificial sequence

<220>
<221> misc_feature
<222> ()..()

100

<223> primer for identifying murine exons 2 and 3

<400> 68

agatcttgag gatccaagac ttgtttctga cttgg

35

<210> 69

<211> 34

<212> DNA

<213> artificial sequence

<220>

<221> misc_feature

<222> ()..()

<223> primer for identifying murine exons 3 and 4

<400> 69

gctgactttg aactcaagag atctgcttta cccc

34

<210> 70

<211> 28

<212> DNA

<213> artificial sequence

<220>

<221> misc_feature

<222> ()..()

<223> primer for identifying murine exons 3 and 4

<400> 70

ctgttgacat attcccaaaa cacgacaa

28

<210> 71

101

<211> 30
<212> DNA
<213> artificial sequence

<220>
<221> misc_feature
<222> ()..()
<223> primer for identifying murine exons 4 and 5

<400> 71
gtcaagggaa aagtaatcct gttgatgctg

30

<210> 72
<211> 27
<212> DNA
<213> artificial sequence

<220>
<221> misc_feature
<222> ()..()
<223> primer for identifying murine exons 4 and 5

<400> 72
tatccacaag aaagagccgt ctgggct

27

<210> 73
<211> 27
<212> DNA
<213> artificial sequence

<220>
<221> misc_feature
<222> ()..()
<223> primer for identifying murine exons 5 and 6

<400> 73

agcccagacg gctctttctt gtggata

27

<210> 74

<211> 34

<212> DNA

<213> artificial sequence

<220>

<221> misc_feature

<222> ()..()

<223> primer for identifying murine exons 5 and 6

<400> 74

ccagcttggg aaccaccagt ccttctgcca tctg

34

<210> 75

<211> 27

<212> DNA

<213> artificial sequence

<220>

<221> misc_feature

<222> ()..()

<223> primer for identifying murine exons 6 and 7

<400> 75

ttccagaggt tggtgagaac agatggc

27

<210> 76

<211> 33

103

<212> DNA

<213> artificial sequence

<220>

<221> misc_feature

<222> ()..()

<223> primer for identifying murine exons 6 and 7

<400> 76

gcgatctcca tttctaccct tttctctccg tcc

33

<210> 77

<211> 28

<212> DNA

<213> artificial sequence

<220>

<221> misc_feature

<222> ()..()

<223> primer for identifying murine exon 7

<400> 77

caagaagaca acgtagaagg acggagag

28

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27

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27

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28

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28

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<223> primer for identifying murine exon 9

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27

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<223> primer for identifying murine exon 8

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gtacatgtca gcagactcca gaaagtc

27

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<223> primer for identifying 3' flanking region of murine exon 9

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27

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<223> primer for identifying 3' flanking region of murine exon 9

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27

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aggccattgc accatcttgg tgaacag

27

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<223> primer for identifying 3' flanking region of murine exon 9

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gatcttacct ttgtccacag ggctctac

28

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<223> primer for obtaining murine promoter

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ccaatgcatc ttttcccagt gggctct

27

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<212> DNA

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<223> primer for isolation of transcription initiation site

<400> 90

cccagaacag atctgactgc ctctttc

27

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<400> 91

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27

<210> 92

<211> 27

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gactggagag agtgctgtcc tccttgc

27

<210> 93

<211> 29

<212> DNA

<213> artificial sequence

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<223> primer for cloning Rhesus alpha 1,3 GT

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gaggtcaagc cagagaagag gtggcaaca

29

110

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<211> 30
<212> DNA
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30

<210> 95
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29

<210> 96
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<220>

111

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<223> primer for cloning Rhesus alpha 1,3 GT

<400> 96

ctggccaaat ggaatgcatg ctgctgactc

30

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